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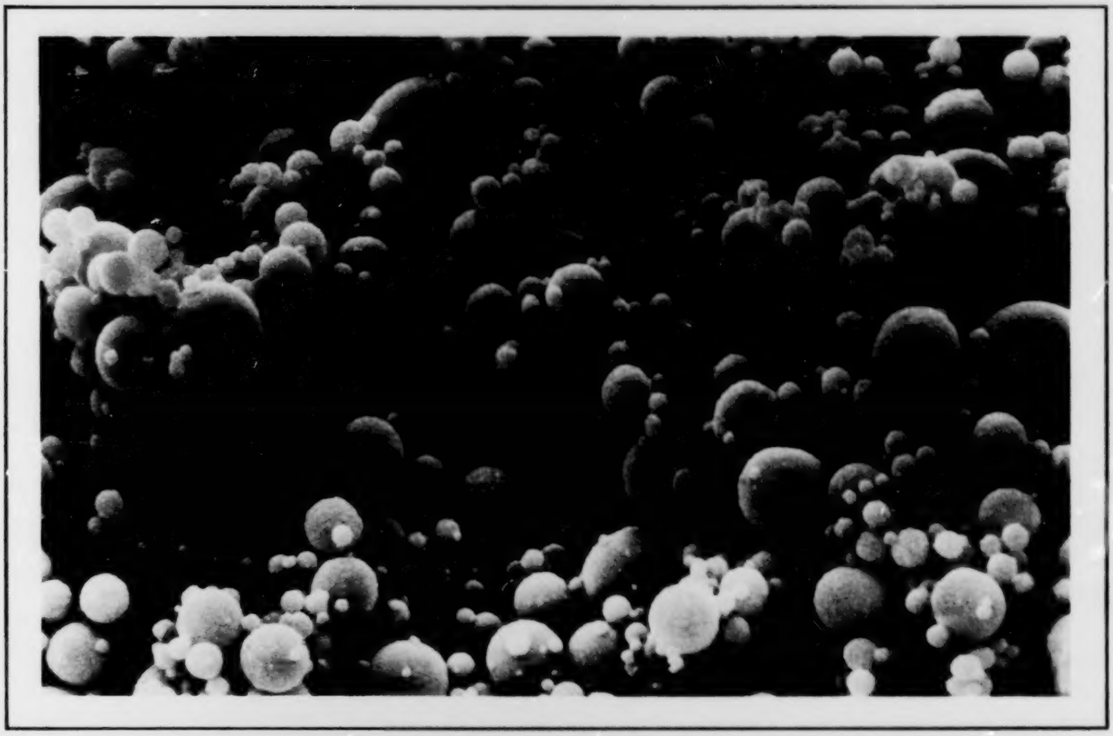
FLY ASH IN CONCRETE



COMPILATION OF ABSTRACTS OF PAPERS FROM RECENT INTERNATIONAL CONFERENCES AND SYMPOSIA ON FLY ASH IN CONCRETE

79pp

V. Sivasundaram and V.M. Malhotra

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V. Sivasundaram and V.M. Malhotra

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FOREWORD

Canada Centre for Mineral and Energy Technology (CANMET) has an on-going research project dealing with the performance of concrete incorporating supplementary cementing materials. These materials are by-products of mining, metallurgical, and electrical industries, and include limestone dust, ferrous and non-ferrous slags, condensed silica fume, and fly ash. Use of these materials in concrete not only helps to impart special properties to concrete and reduce the cement requirements but also solves, to a degree, the solid-waste disposal problem. As a result, considerable data and experience in the use of supplementary cementing materials have been accumulated. This information has been published in a number of research papers. Also, CANMET special publication SP 85-3, entitled "Fly Ash in Concrete", published in 1985, presents a state-of-the-art review of the principal advances in research, development, and practical applications of fly ash in concrete made from 1976 to 1984.

As part of technology transfer and information dissemination, CANMET, in association with the American Concrete Institute (ACI) and several other organizations, sponsored the first and the second CANMET/ACI international conferences on the Use of Fly Ash, Slag, Silica Fume and Natural Pozzolans in Concrete in 1983 at Montebello, Canada, and in 1986 at Madrid, Spain, respectively. The proceedings of those conferences are available from the American Concrete Institute as ACI SP 79 and SP 91.

This volume, which it is hoped will be of use to researchers and engineers involved in the use of fly ash in concrete, presents abstracts of papers from 13 recent international conferences and symposia on fly ash and its use in concrete.

V.M. Malhotra
Head, Construction Materials Section
CANMET

September 1987

PRÉFACE

Le Centre canadien de la technologie des minéraux et de l'énergie (CANMET) travaille actuellement sur un projet qui traite du comportement du béton auquel on incorpore des matériaux additionnels de cimentation. Ces matériaux sont des sous-produits des industries minières, métallurgiques et électriques et comprennent de la poudre de calcaire, des scories ferreuses et non ferreuses, des fumées de silice condensées et des cendres volantes. L'utilisation de ces matériaux dans le béton, non seulement permet d'ajouter des propriétés spéciales au béton et de réduire les besoins de ciment, mais aussi, résout dans une certaine mesure, le problème de l'évacuation des déchets solides. C'est ainsi que dans le domaine de l'utilisation des matériaux additionnels de cimentation le CANMET a acquis beaucoup de données et d'expérience. Ces connaissances ont été publiées dans un certain nombre de mémoires de recherche. La publication spéciale du CANMET SP 85-3 intitulée "Cendres volantes dans le béton" publiée en 1985 présente aussi une mise à jour des principaux progrès de la recherche, du développement et des applications pratiques des cendres volantes dans le béton, accomplis de 1976 à 1984.

Pour faciliter le transfert de technologie et la dissémination des renseignements, le CANMET avec l'American Concrete Institute et plusieurs autres organisations ont patronné les première et seconde conférences internationales conjointes CANMET/ACI sur l'emploi des cendres volantes, des laitiers, des fumées de silice et autres sous-produits minéraux dans la fabrication du béton en 1983 à Montebello, au Canada et en 1986 à Madrid, en Espagne, respectivement. Les comptes rendus de ces conférences (ACI SP 79 et SP 91) sont disponibles à l'American Concrete Institute.

Ce volume contient des résumés de mémoires présentés aux treize derniers symposia et conférences internationaux sur les cendres volantes et leur utilisation dans le béton. Le volume, espérons-le, sera utile aux chercheurs et aux ingénieurs intéressés par l'utilisation des cendres volantes dans le béton.

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Septembre 1987

FLY ASH IN CONCRETE

COMPILATION OF ABSTRACTS OF PAPERS FROM RECENT INTERNATIONAL CONFERENCES AND SYMPOSIA ON FLY ASH IN CONCRETE

by

V. Sivasundaram* and V.M. Malhotra**

Synopsis

This report is a compilation of abstracts of papers from recent international conferences and symposia on the use of fly ash in concrete. The conferences covered include those held in Europe and North and South America between 1980 and 1986. Papers were selected on the basis of their direct relevance to the use of fly ash in concrete. The abstracts are given in chronological order. Keywords for each abstract and an author index are included.

LES CENDRES VOLANTES DANS LE BÉTON

RECUEIL DES RÉSUMÉS DE MÉMOIRES PRÉSENTÉS AUX DERNIERS SYMPOSIA ET CONFÉRENCES INTERNATIONAUX SUR LES CENDRES VOLANTES DANS LE BÉTON

par

V. Sivasundaram* et V.M. Malhotra**

Sommaire

Le présent rapport est un recueil des résumés de mémoires présentés aux derniers symposia et conférences sur l'utilisation des cendres volantes dans le béton. Les conférences couvertes incluent celles tenues en Europe et en Amérique du Nord et du Sud entre 1980 et 1986. Les mémoires ont été choisis en fonction de leur rapport direct avec l'utilisation des cendres volantes dans le béton. Les résumés sont donnés par ordre chronologique. Chaque résumé est accompagné de mots-clés, et l'index des auteurs est inclus.

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Keywords

abrasion resistance; absorption; accelerated curing; accelerated tests; adiabatic temperature rise; air-entrainment; air-void stability; alkali–aggregate reaction; autoclave expansion; Bingham suspension; Blaine method; blast-furnace slag; bleeding; blended cement; Bogue's equations; carbonation; cenospheres; chloride permeability; Class C fly ash; Class F fly ash; CO_2 diffusion; compressive strength; condensed silica fume; correcting creep; corrosion of reinforcement; creep recovery; creep; critical degree of saturation; durability; early-age strength; ettringite; fineness; flash setting; flexural strength; fly ash; fly ash aggregates; fly ash beneficiation; fly ash concrete; fly ash-cement grout; fly ash-lightweight aggregate; fracture toughness; freeze–thaw expansion; geocrete; heat of hydration; high fly ash concrete; hydrothermal reactions; intergrinding; lightweight aggregates; lignite fly ash; load-independent movements; loss on ignition; mass concrete; maturity; microcracking; mineral admixture; mineralogy; mixture-proportioning; modulus of elasticity; morphology; natural pozzolans; nondestructive testing; Omega index Factor; partial cement replacement; particle size distribution; peat ash; permeability; phenolphthalein test; plant-batching; plerospheres; porosity; pozzolanic activity index; pozzolanic reaction; pulse velocity; pulverized fuel ash (PFA); pumpability; ready-mixed concrete; R factor; relative dynamic modulus; resonance frequency; rheology; rice-husk ash; roller-compacted concrete; scaling; scanning electron microscopy; sea-water attack; segregation; setting time; shape factor; shotcrete; shrinkage; splitting tensile strength; standard creep; steam-curing; stress intensity factor; structural concrete; sub-bituminous fly ash; sulphate resistance; superplasticizer; tensile strength; thermal analysis; thermal conductivity; thermal expansion; X-ray methods; water-to-cement ratio; workability.

INTRODUCTION

During the past seven years a number of conferences and symposia have been conducted on the use of fly ash and other mineral by-products in portland cement concrete. The most notable have been the following:

- Seventh International Congress on the Chemistry of Cement; Paris, 1980
- Fifth International Symposium on Concrete Technology; Monterrey, Nuevo Leon, Mexico, March 1981
- Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, November 1981
- EPRI Workshop on Research and Development Needs for Use of Fly Ash in Cement and Concrete; Palo Alto, California, March 1982, (proceedings EPRI Report CS-2616-SR, September 1982)
- Sixth International Symposium on Fly Ash Utilization; Reno, Nevada, March 1982
- International Symposium on the Use of PFA in Concrete; University of Leeds, England, April 1982
- First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag, and Other Mineral By-Products in Concrete; Montebello, Canada, July–August 1983, (published as ACI Special Publication SP-79)
- AshTech '84: Second International Conference on Ash Technology and Marketing; London, September 1984
- Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal I; Materials Research Society, Boston, November 1984
- Seventh International Ash Utilization Symposium and Exposition; Orlando, Florida, March 1985
- ACI-RILEM Symposium 85: Technology of Concrete When Pozzolans, Slags and Chemical Admixtures are Used; Monterrey, Nuevo Leon, Mexico, March 1985
- Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II; Materials Research Society, Boston, December 1985
- Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete; Madrid, Spain, April 1986.

Abstracts of selected papers from these sources have been compiled in this volume to bring to the attention of concrete engineers and researchers the availability of the large quantity of published material on this subject.

For this compilation, papers have been selected on the basis of their direct relevance to the practical application of fly ash to concrete construction. The reader is urged to consult the original proceedings of these meetings for detailed consideration of the subject and to review the many excellent papers on research and other aspects of the subject not directly applicable to concrete construction.

CONTENTS

FOREWORD i
PRÉFACE iii
SYNOPSIS v
SOMMAIRE v
KEYWORDS vii
INTRODUCTION ix

1980: ABSTRACT 1
Seventh International Congress on the Chemistry of Cement 1
1981: ABSTRACTS 2–9
Fifth International Symposium on Concrete Technology .... 1 – 3
1981: ABSTRACTS 10–23
Symposium on Effects of Fly Ash Incorporation in Cement and Concrete .... 3 – 8
1982: ABSTRACTS 24–28
Electric Power Research Institute Workshop on Research and Development Needs for Use of Fly Ash in Cement and Concrete .... 8 – 9
1982: ABSTRACTS 29–34
Sixth International Symposium on Fly Ash Utilization .... 10 – 11
1982: ABSTRACTS 35–50
International Symposium on the Use of PFA in Concrete .... 11 – 14
1983: ABSTRACTS 51–72
First CANMET/ACI International Conference on The Use of Fly Ash Silica Fume, Slag and Other Mineral By-products in Concrete .... 15 – 23
1984: ABSTRACTS 73–98
AshTech '84: Second International Conference on Ash Technology and Marketing .... 24 – 31
1984: ABSTRACTS 99–104
Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal .... 32 – 34
1985: ABSTRACTS 105–122
Seventh International Ash Utilization Symposium and Exposition .... 34 – 40
1985: ABSTRACTS 123–140
ACI-RILEM Symposium 85: Technology of Concrete When Pozzolans, Slags and Chemical Admixtures are Used .... 40 – 46
1985: ABSTRACTS 141–149
Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II .... 46 – 49
1986: ABSTRACTS 150–193
Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete .... 49 – 65

AUTHOR INDEX 67

1980
Seventh International Congress on the Chemistry of Cement
Paris, 1980

1. Owens, P.L., and Buttler, F.G. "The reaction of fly ash and portland cement with relation to the strength of concrete as a function of time and temperature"; Seventh International Congress on the Chemistry of Cement, Paris, Vol.3, 1980, IV.60 – IV.65.

When portland cement concrete is subjected to rises in temperature, due to the effect of heat of hydration of cement, the long-term strength and durability of the concrete are usually adversely affected. But, with fly ash concrete, the strength increases with increases in both maturity and fly ash content. This paper reports on a test program conducted to investigate the effects of different curing regimes on fly ash–cement mortar strength and the quantity of lime in the hydrate. The test results indicate that the adverse effects of high curing temperatures on the strength of portland cement mortars can be related to the amount of lime in the hydrate, and gains in strength are likely to occur in high temperature environments, with portland cement–fly ash combinations. Even with 75 per cent replacement of cement by fly ash, the amount of residual lime in the hydrate is found to be sufficient to inhibit corrosion of embedded steel reinforcement.

Keywords: *fly ash concrete; strength; maturity: curing temperature; cement hydrate; residual lime; corrosion protection.*

1981
Fifth International Symposium on Concrete Technology
Monterrey, Nuevo Leon, Mexico, March 1981

2. Mehta, P.K. "Sulphate resistance of blended portland cements containing pozzolans and granulated blast furnace slag"; Fifth International Symposium on Concrete Technology, Monterrey, Nuevo Leon, Mexico, March 1981, pp. 35–50.

This paper presents a laboratory investigation undertaken to determine the relationship between sulphate resistance and microstructure of hydrated cements in order to clarify the factors governing the behaviour of cements exposed to sulphate attack. Blended portland cements made with several pozzolanic materials, namely, a natural pozzolan, a fly ash, a rice-husk ash, and a granulated blast-furnace slag were used in this study. Blended cement pastes were subjected to sulphate resistance evaluation following 28 days of moist curing. From the results, it is concluded that the differences in pore size distribution of hydrated cement, rather than chemical composition, played a dominant role in determining the sulphate-resisting behaviour of blended portland cements.

Keywords: *sulphate resistance; blended cements; pore size distribution; microstructure; pozzolanic reaction; pore refinement.*

3. Tassios, T.P. "Greek lignite fly ashes as cement substitute"; Fifth International Symposium on Concrete Technology, Monterrey, Nuevo Leon, Mexico, March 1981, pp. 71–83.

This paper presents the initial results of a long-term study, in which the potential of two Greek lignite fly ashes (LFA) as partial replacement for cement in concrete is investigated. The origin, fineness, method of incorporation in concrete, and cement replacement levels of the fly ashes were studied, and properties such as compressive and tensile strengths, shrinkage, heat of hydration, corrosion of embedded steel in fly ash concrete, resistance of fly ash concrete to sea-water attack were investigated. The test results indicate that strength is only slightly affected by low percentages of LFA. Better results were obtained when LFA is used as a partial replacement of cement in concrete compared to the case where LFA is ground together with clinker. Shrinkage of concrete was not significantly affected with the incorporation of fly ash. Long-term durability results are not presented in this paper.

Keywords: *lignite fly ash; partial cement replacement; fineness; compressive strength; tensile strength; heat of hydration; shrinkage.*

4. Philleo, R.E. "Natural pozzolan and fly ash in mass concrete"; Fifth International Symposium on Concrete Technology, Monterrey, Nuevo Leon, Mexico, March 1981, pp. 145–157.

This paper reviews the experience of the Corps of Engineers on the use of natural pozzolan and fly ash in mass concrete work. The historical development of the use of fly ash in mass concrete as well as the present policy of the Corps on this subject is described. The future concerns of the Corps of Engineers regarding the effective utilization of sub-bituminous and lignite fly ashes in concrete, sulphate resistance of cement–pozzolan blends, and the use of pozzolans to combat alkali–aggregate reaction in concrete are discussed.

Keywords: *fly ash; natural pozzolans; mass concrete; optimum pozzolan replacement; sulphate resistance; alkali-aggregate reaction.*

5. Mather, B. "Blends of cementitious materials for concrete to be exposed to sea water"; Fifth International Symposium on Concrete Technology, Monterrey, Nuevo Leon, Mexico, March 1981, pp. 289–310.

With the increasing cost of energy and hence of energy-intensive products such as portland cement clinker, increased attention is properly being given to the use of blends of portland cement with other materials for purely economic considerations. In sea-water exposures, concrete needs to be resistant to wetting and drying and to moderate sulphate attack. It usually must also be of low permeability to protect reinforcement from corrosion. Available laboratory data and field experience both indicate that blends of portland cement and pozzolan or portland cement and pulverized quenched iron blast-furnace slag have benefits for sea-water exposure in addition to the reduced cost that should make them initially attractive. With these relations in mind, the factors relevant to the use of these materials and the properties of concrete affected by exposure to sea water are reviewed.

Keywords: *blast furnace slag; blended cements; pozzolans; reinforcement corrosion; sea water; sulphate attack; wetting and drying.*

6. Kanitakis, I. "Permeability of concrete containing pulverized fuel ash"; Fifth International Symposium on Concrete Technology, Monterrey, Nuevo Leon, Mexico, March 1981, pp. 311–322.

The main aim of this work was to investigate whether English-produced PFA (pulverized fuel ash) concretes are impervious enough to be used for offshore structures. A representative OPC (ordinary portland cement) concrete of high cement content and a corresponding PFA concrete were tested. These two mixes were designed to have basically the same workability and cube strength, so that their permeability could be compared. The ISAT-test (as defined in BS 1881, Part 5, 1970-6. Test for determining the Initial Absorption of Concrete) was adopted and measurements of the permeability were taken at 7, 17, 28, and 56 days. The results showed that the OPC mix has lower permeability than the PFA mix at early ages, but the difference tends to diminish at later ages. Detailed test results are reported in suitable form and discussed.

Keywords: *absorption; offshore structures; permeability; portland cement; pulverized fuel ash; workability.*

7. Scanlon, J.M. "Mixture-proportioning of concrete containing natural pozzolans, fly ashes, and slags for use in seawater" Fifth International Symposium on Concrete Technology, Monterrey, Nuevo Leon, Mexico, March 1981, pp. 323–349.

This paper discusses the mixture-proportioning of concrete containing natural pozzolans, fly ashes, and slags for use in sea water. Procedures for proportioning concrete to assure adequate quality, durability, and placeability are discussed. The water-to-cement ratio is emphasized, and the methodology of computing effective water-to-cement ratios by volume when using natural pozzolans, fly ashes, and slags is reviewed. It is concluded that the mixtures should be proportioned on a partial cement replacement by the natural pozzolans, fly ashes, or slags on a volumetric basis, if it is acceptable that the concrete achieve its desired strength at approximately 90 days. If early-age strength equivalent to that of portland cement concrete is required, the mixtures should be proportioned on a partial replacement plus an equivalent amount of natural pozzolan, fly ash, or slag to replace a similar volume of fine aggregate.

Keywords: *mixture-proportioning; sea-water attack; fly ash; natural pozzolans; slags; water-to-cement ratio; partial replacement by absolute volume; placeability; durability.*

8. Munn, R.L., and Ryan, W.G. "Concretes in Australia containing fly ashes and/or slags: their properties and performance in aggressive environments"; Fifth International Symposium on Concrete Technology, Monterrey, Nuevo Leon, Mexico, March 1981, pp. 369–392.

This paper reviews the Australian experience on the durability of concrete incorporating fly ashes and/or slags under aggressive service conditions. Data are presented from case histories and laboratory investigations into compressive strength development and durability characteristics of a wide range of concretes utilizing slags and fly ashes. In many cases, comparison is made between the performance of concretes containing slags and fly ashes and that of traditional concretes subjected to similar conditions. The studies indicate that, provided concretes are given adequate curing and compaction, pozzolanic binders play an important role in improving durability of concretes for buildings and marine structures. It is concluded that with appropriate mix design, concretes containing slags and fly ashes can match the properties of conventional concretes in all respects.

Keywords: *blast-furnace slag; fly ash; compressive strength; slag aggregates; tertiary blends; mix design methods; freeze–thaw expansion; sulphate resistance; creep; shrinkage; durability.*

9. Cabrera, J.G., and Plowman, C. "The influence of pulverized fuel ash on the early and long-term strengths of concrete"; Fifth International Symposium on Concrete Technology, Monterrey, Nuevo Leon, Mexico, March 1981, pp. 599–610.

This paper presents a study of the early and long-term strengths of concrete mixes prepared with four British pulverized fuel ashes used as partial replacement of ordinary portland cement. The mechanism and reactions responsible for changes in the unconfined compressive strength were studied by XRD of C_3A and C_4AF extracted from the ordinary portland cement and hydrated with PFA and with inert ground quartz. It is shown that the replacement of cement up to 30% with hopper ashes resulted in higher long-term (91 days) strengths as compared with the concretes without PFA. The conditioned PFA performed poorly in relation to its cement–concrete counterpart. Hopper ashes gave higher early strengths at varying percent replacements. It is proposed that the mechanism by which strength changes is twofold: a) a physical effect which depends on the shape and specific surface of the PFA, and b) a chemical effect consisting of two distinct reactions: (1) a retardation of the hydration of C_3A and C_4AF which effectively reduces the heat of hydration and encourages the formation of silicate hydrates, and (2) a proper pozzolanic reaction which was detected as early as three days of age by the use of a scanning electron microscope.

Keywords: *pulverized fuel ash; unconfined compressive strength; pozzolanic reaction; cement hydration; retardation of hydration; particle size distribution.*

1981

Symposium on Effects of Fly Ash Incorporation in Cement and Concrete Materials Research Society, Boston, USA, November 1981

10. Ravina, D. "Production and collection of fly ash for use in concrete"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 2–11.

This paper describes the set-up, processes, and operations involving fly ash at an electrical power station from a viewpoint of their effect on the properties of fly ash. The systems for collection, handling, beneficiation, and storage are analysed and their effect on the fly ash is evaluated. It is concluded that the final properties of the fly ash are closely related to the mode of operation of the various systems of the power plant. A positive approach to fly ash, namely, as a resource material rather than a waste by-product, and proper design of the collecting systems with a view to utilization, instead of disposal, will lead to significant improvement in the quality of fly ash and permit increased consumption of fly ash by the concrete industry.

Keywords: *beneficiation; collection; fly ash; handling; storage.*

11. Wesche, K., and vom Berg, W. "Properties of fly ash used in Germany"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 45–53.

According to the German standard for concrete constructions (DIN 1045), fly ashes having prior approval only can be used as a concrete admixture. This approval is granted to the fly ash of a single boiler if it fulfils a set of requirements. The properties of all fly ashes used in concrete must be continuously inspected. This paper reports on a survey carried out on the properties of coal fly ashes from 14 power plant boilers, based on the large number of tests performed in connection with this continuous monitoring. This survey contains information about chemical compositions and physical and mineralogical properties of fly ashes and some relevant properties of cement pastes and mortars containing fly ash. In addition, correlations between different fly ash properties are given, and these properties are discussed with regard to the use of fly ash in concrete and to the current quality control of fly ash.

Keywords: *fly ash properties; loss on ignition; specific surface; chemical composition; pozzolanic activity index; compressive strength.*

12. Buttler, F.G. "Effect of reaction between pulverized fuel ash and calcium hydroxide on concrete properties"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 155–164.

This paper describes the effect of the pozzolanic reaction between pulverized fuel ash and calcium hydroxide liberated from the hydration of portland cement, and of the water-reducing properties of pulverized fuel ash on the properties of concrete. Emphasis is placed on the quantities of the CSH gel and portlandite present after different curing times and different curing cycles. Some discussion also is included, pertinent to the test methods employed when comparing concretes made with and without pulverized fuel ash additions, particularly with reference to sulphate resistance and alkali–silica reaction.

Keywords: *pulverized fuel ash, pozzolanic reaction, CSH gel, cement hydration, alkali–silica reaction, sulphate resistance, curing temperature.*

13. Dodson, V.H. "The effect of fly ash on the setting time of concrete – chemical or physical"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 166–171.

One of the principal objections to the use of fly ash in concrete is its effect on the setting time of concrete. In most cases, fly ash concrete requires a longer time to set than the reference mix. The objective of this study is to use the setting time and the Omega Index Factor (O.I.F.) of portland cement concretes and fly ash concretes to determine the mechanism whereby fly ash affects setting time. The O.I.F. of a given concrete is obtained by dividing the cement factor of the concrete by its water-to-cement ratio. In this study, the initial and final setting times were measured, according to Standard ASTM methods, on concretes made incorporating three cements and three fly ashes. The test results indicate that the setting time of portland cement concretes made from the same materials is linearly related to the O.I.F. of the concretes. This straight line, or base line, is then used to determine whether a given fly ash is altering the setting time of concrete by chemical processes, or by the result of what was done to the concrete to accommodate the fly ash, i.e., lowered cement factor and increased water-to-cement ratio. If the setting time data point for the fly ash concrete falls on the base line, its setting time is the result of the physical aspect. When the data point falls significantly below or above the base line, chemical interactions between cement and fly ash, or between the fly ash and water, in addition to the physical effects, are influencing the setting time of the concrete.

Keywords: *fly ash; mix proportions; setting time; cement factor; water-to-cement ratio; Omega Index Factor; fly ash concrete.*

14. Ravina, D. "Fly ash concrete under hot weather conditions"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 172–183.

This paper deals with the effect of elevated temperature on the properties of fresh and hardened fly ash concretes. Hot weather gives rise to problems in manufacturing, placing, and curing portland cement concrete, in that it can adversely affect the properties and serviceability of the hardened material. Fly ash (Class F) from bituminous coal, by its nature, has a lower reaction rate compared to portland cement, thus developing its cementitious properties more slowly. This feature and its consequences, which are regarded as disadvantages in a moderate and particularly in a cold climate, may be beneficial in a hot one, and alleviate some of the problems and difficulties in hot- weather concreting. In this study, concrete mixtures were made with replacements of cement by fly ash up to 30 per cent and cast at 20°C (68°F) and 40°C (104°F). The slump decrease was found to be smaller in the fly ash concretes, and the amount of mixing water required to maintain a given slump at elevated temperature had to be increased in fly ash concrete as well. Further, the compressive strength of fly ash concrete with a constant water content was not affected by elevated temperature, while the strength of a constant consistency (slump) fly ash concrete was reduced.

Keywords: *hot-weather construction; increased water demand; fly ash concrete; compressive strength; slump loss.*

15. Dodson, V.H. "The strength contribution of fly ash concrete – a new approach to its estimation"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 184–193.

The objective of this investigation was to use the Omega Index Factor (O.I.F.) concept, as it pertains to both plain and fly ash concretes, as a means of separating the strength contribution of the fly ash from that of the cement in fly ash concrete. When the same materials (i.e., cement, sand, coarse aggregate) and curing conditions are employed in fabricating a series of non-admixture concretes, the compressive strengths of those concretes, at any age of tests, are a straight-line function of their Omega Index Factor. The O.I.F. of a given concrete is obtained by dividing its cement factor by the water-to-cement ratio.

The position and slope of the x–y plot of compressive strength versus O.I.F. varies with different cements. The straight-line plots for the plain concretes are then used to evaluate a given fly ash. For example, when concretes, in which a portion of the cement is replaced with fly ash, are subjected to this type of analysis, the fly ash concrete data point will fall either on the straight-line plots for the plain concretes, indicating no strength contribution, or above the straight-line plots, indicating a definite strength contribution. The distance of the fly ash data point from the base line at the same O.I.F. can be used to estimate the magnitude of the strength contribution of the fly ash.

The strength contributions of several different fly ashes to concrete are reported and compared with the strength contribution of portland cement at the same ages of test.

Keywords: *fly ash; fly ash concrete; compressive strength; Omega Index Factor; fly ash strength contribution.*

16. Ong, L.T., Munday, J.G.L., and Dhir, R.K. "Moisture related movements in OPC/PFA concrete"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 204–213.

The paper deals with moisture-related movements in OPC/PFA concretes caused by continuous drying and alternate wetting and drying, comparison being sought with the corresponding OPC concretes. It is shown that drying shrinkage is related to the equivalent cement content of the concrete, but cannot be related to any other single fly ash characteristic. There is an optimum level of cement replacement by fly ash which improves the resistance of concrete to wetting/drying expansion.

Keywords: *drying shrinkage; fly ash; moisture-related movements; wetting and drying.*

17. Crow, R.D., and Dunstan, E.R., Jr. "Properties of fly ash concrete"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 214–224.

The following aspects of fly ash concrete are discussed in this paper: (i) fly ash properties with regard to ASTM/ANSI designation C 618, (ii) properties of concretes containing these fly ashes at 15 to 25 per cent replacement of portland cement by weight, (iii) properties of concretes containing no portland cement and having fly ash as the primary cementing medium. Properties discussed and compared include sulphate resistance, compressive strength, drying shrinkage, and freeze–thaw durability. Fly ash is used with portland cement by the United States Bureau of Reclamation in most current concrete construction. Future research plans at the Bureau include further investigation and evaluation of high fly ash cements.

Keywords: *Class F fly ash; Class C fly ash; fly ash concrete; elastic properties; drying shrinkage; adiabatic temperature rise; sulphate resistance.*

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18. Wesche, K. and Schubert, P. "Properties of mortars and concrete made with fly ash"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 225–232.

Fly ashes from bituminous coals have been used as admixtures to concrete in the Federal Republic of Germany during the past 15 years. A fly ash is permitted as concrete admixture only if it fulfils certain requirements in relation to chemical composition and mineralogical properties as well as strength and durability in concrete according to German standard DIN 1045. This paper reports the results of some of the research programs on fly ash concrete in the Federal Republic of Germany. The principal results obtained are as follows:

The greater the fly ash content, the lower the strength at early ages. The strength lag of the mortar or concrete with fly ash diminishes with increasing age. The modulus of elasticity of concretes with fly ash was higher than the modulus of concretes without fly ash. Shrinkage and resistance to freezing and thawing of mortars or concretes made with fly ash were not appreciably different from those made without fly ash. A replacement of cement by fly ash to about 50 per cent increases the resistance to sulphate, especially when cement with a lower sulphate resistance is used. For an equal reference compressive strength, the carbonation behaviour of mortars and concretes containing fly ash is generally not appreciably different from the carbonation behaviour of concretes made without fly ash.

Keywords: *compressive strength; flexural strength; maturity; carbonation, fly ash; freezing and thawing resistance; mortars; shrinkage; strength at early ages; sulphate resistance.*

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19. Ramakrishnan, V., Coyle, W.V., Brown, J., Tlustus, P.A., and Venkataramanujam, P. "Performance characteristics of concretes containing fly ash"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 233–242.

This paper presents the results of a performance evaluation study of concrete containing fly ash. The properties of fly ash concrete have been compared with their corresponding properties of regular concrete. The plastic properties of concrete compared are slump, air content, vebe-time, temperature, unit weight, and setting time of concrete. The hardened concrete properties compared are unit weight, compressive strength, splitting tensile strength, flexural strength, static modulus of elasticity, dynamic modulus of elasticity, pulse velocity, and absorption coefficient. These properties are compared at four different ages: 3, 7, 28, and 90 days. Durability under rapid freeze–thaw conditions and shrinkage deformations are also discussed.

A comparison of the physical properties of fresh concrete, on the basis of approximately equal slump and entrained air, has shown the relative ease of placing and finishing of concretes containing fly ash. The rate of stiffening is lower for fly ash concretes containing Type I cement.

In general, fly ash concretes show higher strengths and higher modulus values at 90 days than their corresponding regular concretes. However, fly ash concrete has slightly higher drying shrinkage than regular concrete. The strength and elastic modulus relationships are approximately the same for both concretes.

Keywords: *workability; air entrainment; setting time; compressive strength; flexural strength; splitting tensile strength; modulus of elasticity; pulse velocity; freeze–thaw resistance; shrinkage.*

20. Cain, C.J. "Effects of various types of fly ash on the behaviour and properties of concrete"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 260–268.

This paper discusses the effects of four types of fly ash on the three major categories of concrete, namely, mass, structural and paving, and pre-cast. The fly ashes discussed are Class F low loss on ignition, Class F high loss on ignition, Class C moderately cementitious, and Class C highly cementitious. Aspects of concrete production such as economy, workability, strength, and durability are examined in light of the chemical and physical characteristics of the four designated types of fly ash and their effects when added to concrete mixes. Class F fly ashes, those from anthracite and bituminous coals are reported on primarily for their low or high loss on ignition. Class C fly ashes, usually collected from the burning of sub-bituminous and lignite coals, are presented from the perspective of their CaO content and resulting cementitiousness or hydraulicity.

Keywords: *Class F fly ash; Class C fly ash; loss on ignition; cementitious properties; workability; water reduction; heat of hydration; air-entrainment; sulphate resistance; strength gain.*

21. Barker, W.R. "The distinction between water reduction and reactivity as the factors influencing fly ash performance in concrete"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 289–295.

Present specifications for fly ash rely on compliance with minimum or maximum levels for various physical and chemical properties. Even within these bounds, wide differences in performance between alternative materials are found. This paper reports on a test program devised to evaluate the performance of South African fly ashes in concrete mixes. The program was developed to evaluate fly ashes in terms of two parameters: "cementing efficiency" or reactivity index, and water reduction of fly ash in concrete. Test data using this approach showed marked difference in performance of concrete made using two fly ashes which were thought to be basically similar. The study concludes that existing specifications for fly ash do not define its performance in concrete and that the influence of fly ash on the rheology of concrete is inadequately understood.

Keywords: *fly ash specifications; cement–fly ash blends; cementing efficiency; water reduction; fineness; loss on ignition; rheology of concrete.*

22. Raba, C.F., Jr., Smith, R.L., and Mearing, M. "Sub-bituminous fly ash utilization in concrete"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 296–305.

The uses of bituminous fly ash as a mineral admixture for portland cement concrete has been well documented over the years. Sub-bituminous fly ash, in comparison, has only recently begun to experience widespread utilization in the concrete products market. Therefore, only a limited amount of information on this Class C fly ash has been made available to architects, engineers, ready-mixed concrete producers and contractors. This paper presents mix designs using various ash replacement values for combinations of different cements, aggregates and organic admixtures. The compressive strength of the concrete is found to vary considerably depending on the compatibility of the concrete constituents. The inclusion of fly ash results in continued strength gain over a long period of time. Partial replacement of cement by sub-bituminous fly ash delays the hardening of concrete. It is concluded that sub-bituminous fly ash is a mineral admixture which improves concrete. The effectiveness of the fly ash in concrete depends on the unique physiochemical compatibility of the cement, fly ash, aggregate and chemical admixtures.

Keywords: *Class C fly ash; compressive strength; mineral admixtures; mixture-proportioning; portland cement; sub-bituminous fly ash.*

23. Martin, R., and Hilton, R.G. "A successful application of the use of fly ash in specification air-entrained concrete"; Symposium on Effects of Fly Ash Incorporation in Cement and Concrete; Materials Research Society, Boston, 1981, pp. 306–314.

This paper discusses the performance of ready-mixed concrete incorporating Class F fly ash used for the construction of a large facility in Ohio. The above air-entrained concrete was batched at an offsite plant and mixed and delivered by truck mixer. The paper presents test data documented for nearly 18 months, and variability of the following concrete properties is analysed: strength at 7 and 28 days, cylinder weight at 7 days, air content, slump, concrete temperature, and time between sampling and leaving plant. The test data indicate that the use of fly ash need not present problems in air-entrained concrete if the concrete is properly made and tested.

Keywords: *ready-mixed concrete; Class F fly ash; air-entrainment; slump control; water-to-cement ratio; compressive strength; concrete temperature.*

1982

Electric Power Research Institute Workshop on Research and Development Needs for Use of Fly Ash in Cement and Concrete, Palo Alto, California, USA

March 1982

24. Sturrup, V.R. "A review of the use of Ontario Hydro fly ash in concrete"; Electric Power Research Institute Workshop on Research and Development Needs for Use of Fly Ash in Cement and Concrete; Palo Alto, California, March 1982; Electric Power Research Institute Report CS-2616-SR, 1980, pp. 3.12–3.24.

A review is presented summarizing the history of the use of fly ash by Ontario Hydro in concrete construction since 1950. Information on major structures incorporating fly ash is given. A discussion is presented on research activities conducted by Ontario Hydro. These include studies of carbon in fly ash, concrete mixture-proportioning, creep, and durability.

Keywords: *air-entrainment; alkali–aggregate reaction; carbon; fly ash; mass concrete; mixture-proportioning; pozzolan; quality control.*

25. Norholm, A., and Osbaeck, B. "Fly ash usage and related R&D activities in Denmark"; Electric Power Research Institute Workshop on Research and Development Needs for Use of Fly Ash in Cement and Concrete; Palo Alto, California, March 1982; Electric Power Research Institute Report CS-2616-SR, 1980, pp. 3.25–3.36.

This paper presents a review of the production and use of fly ash in Denmark. Danish standards are reported to permit the use of up to 5 per cent fly ash in all portland cements. Fly ash is also used in the manufacture of cement clinker. Related R&D activities are discussed, including ash characterization, health hazards, quality control, mixture-proportioning, and concrete properties.

Keywords: *characterization; fly ash; health hazards; mixture-proportioning; pozzolan; quality control.*

26. Owens, P.L. "Status of fly ash in UK cement and concrete"; Electric Power Research Institute Workshop on Research and Development Needs for Use of Fly Ash in Cement and Concrete; Palo Alto, California, March 1982; Electric Power Research Institute Report CS-2616-SR, 1980, pp. 3.37–3.47.

The accumulation of research and experience and the progress of British standards and codes of practice have led to a wider engineering appreciation of the benefits that fly ash of controlled quality can give to structural concrete. It is clear that to define fly ash as a pozzolana leads to confusion and that it is better to define it as "fly ash" as is done with blast-furnace slag. It is with this in mind that RILEM has just established a new technical committee, 67-FAB "Use of Fly Ash in Building."

Keywords: *blast-furnace slag; British standards; concrete; fly ash; pozzolan; structural concrete.*

27. Kruger, J.E., Rossouw, E., and van Dijk, J. "The use of PFA in cement and concrete: research and utilization in the Republic of South Africa"; Electric Power Research Institute Workshop on Research and Development Needs for Use of Fly Ash in Cement and Concrete; Palo Alto, California, March 1982; Electric Power Research Institute Report CS-2616-SR, 1980, pp. 3.48–3.58.

A review of South African work is presented and the following points are discussed:

(a) The production of PFA in South Africa is approaching 10 million tons per annum and is expected to double by the end of the century.

(b) South African PFA has similar properties to those reported for overseas PFA of similar composition.

(c) Its pozzolanic activity index correlates better with the percentage residue on a 45 micron sieve than with the specific surface.

(d) In the presence of lime, under moist conditions and at ambient temperatures, it develops strength only very slowly.

(e) Cement–PFA blends produced by intergrinding develop better strength than blends produced by mixing.

(f) Replacement of a part of the portland cement with fine PFA gives mortars increased resistance to attack by sulphates and by soft water, and it affords a significant reduction in the expansion caused by the alkali–aggregate reaction.

(g) The use of PFA, especially in lean concrete, can lead to more economical mixes.

Keywords: *alkali–aggregate reaction; blended cement; concrete; intergrinding; lime; mortars; PFA; pozzolanic activity; Republic of South Africa; research; sulphate resistance.*

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28. Snel, A. "Fly ash production and utilization in the Netherlands; Electric Power Research Institute Workshop on Research and Development Needs for Use of Fly Ash in Cement and Concrete; Palo Alto, California, March 1982; Electric Power Research Institute Report CS-2616-SR, 1980, pp. 3.67–3.79.

A general overview of ash production and utilization in the Netherlands is presented in this paper. Fly ash is used in the manufacture of cement clinker and in blended cements. Some aspects of the effects of fly ash on concrete properties are discussed.

Keywords: *blended cement; Holland; intergrinding; pozzolan; research.*

1982
Sixth International Symposium on Fly Ash Utilization Reno, Nevada, USA, March 1982

29. Rosnerl, J.C., Chehovits, J.G., and Warburton, R.G. "Sulphate resistance of mortars using fly ash as a partial replacement for portland cement"; Sixth International Symposium on Fly Ash Utilization, Reno, Nevada, 1982, Vol. 1, pp. 37–56.

This paper presents a study carried out comparing the sulphate resistance of mortars containing fly ash as a partial cement replacement with control mortars. Three different Class F fly ashes and one Class C fly ash were used with ASTM Type II cement. A test procedure developed at the Waterways Experiment Station, U.S. Army Corps of Engineers, was used, in which the mortar bars were subjected to a mixed sodium and magnesium sulphate solution environment. Measurements of length change, weight change, porosity, and relative dynamic modulus were made for 360 days of immersion. The test results indicate that improvements in sulphate resistance over that provided by a Type II moderate sulphate resistance cement may be obtained through the use of certain fly ashes in concrete. The R factor of the fly ashes tested predicted which of the ashes would improve sulphate resistance.

Keywords: *fly ash; sulphate expansion; pozzolanic reaction; sulphate resistance testing; porosity; relative dynamic modulus; R factor; weight loss.*

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30. Smith, R.L., Raba, C.F., Jr., Mearing, M.A. "The utilization of Class C fly ash in concrete"; Sixth International Symposium on Fly Ash Utilization, Reno, Nevada, 1982, Vol. 1, pp. 164–189.

The utilization of Class F fly ash as a mineral admixture in portland cement concrete has been well established. Class C fly ash, in comparison, has only recently experienced widespread use as a concrete admixture. Although its utilization in concrete products has experienced considerable success in the field, only a limited amount of information on Class C fly ash has been made available to engineers, ready-mixed producers and contractors. This paper discusses in detail the utilization of one Class C fly ash in concrete. This fly ash is produced at a Texas power plant which uses Wyoming sub-bituminous coal as fuel, and the resulting fly ash possesses sufficient calcium oxide to harden in the presence of water. Data are presented on the effect of the fly ash content and mixing temperatures on the engineering properties of plastic and hardened concrete.

Keywords: *Class C fly ash; concrete; engineering properties; mineral admixture; mixing temperatures; plastic and hardened concrete.*

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31. Ashby, J.B. "Answers to the objections to the use of fly ash in concrete"; Sixth International Symposium on Fly Ash Utilization, Reno, Nevada, 1982, Vol. 1, pp. 246–258.

There have been a number of reasons given by specifiers for not allowing the use of fly ash in concrete covered by their specifications, by concrete producers for not using fly ash in their product, and by other groups and individuals not allowing the use of fly ash in concrete over which they have the say on what ingredients are used. This paper critically reviews those reasons that are most frequently used and presents a realistic look at the facts. The following aspects of fly ash concretes are discussed: early-age strength gain, setting time, air-entrainment, variability of fly ash, corrosion protection, and sulphate resistance.

Keywords: *fly ash; specifications; compressive strength; chemical admixtures; setting time; air-entrainment; loss on ignition.*

32. Joshi, R.C. "Effect of coarse fraction (+ #325) of fly ash on concrete properties"; Sixth International Symposium on Fly Ash Utilization, Reno, Nevada, 1982, Vol. 2, pp. 77–85.

This paper presents a laboratory investigation conducted to evaluate the effect of coarse fraction (+ #325) of sub-bituminous fly ashes on the compressive strength and setting time of fly ash concrete. One objective of the study was to determine if removal of coarse fraction would beneficiate the ash. Sub-bituminous fly ashes, produced in Sundance power plant in Alberta, containing varying amounts of coarse fraction (+ #325), were used in the concrete mixes. The test results indicate that, for the ashes tested, the coarse fraction does not seem to influence the ultimate strength and setting time to a significant degree. It is concluded that, in general, removal and/or reduction in coarse fraction beneficiates even the self-cementitious sub-bituminous fly ash.

Keywords: *coarse fraction of fly ash (+ #325); fly ash beneficiation; sub-bituminous fly ash; compressive strength; setting time.*

33. Pierce, J.S. "Use of fly ash in combating sulphate attack in concrete"; Sixth International Symposium on Fly Ash Utilization, Reno, Nevada, 1982, Vol. 2, pp. 208–231.

The paper describes sulphate attack in concrete and outlines its geographical concern to the United States Bureau of Reclamation (USBR). Examples of its destructive nature are shown. USBR testing procedures used to evaluate sulphate resistance are described. Current specification requirements for sulphate environments are listed, and how fly ash qualifies for these environments is discussed. A proposal for the ultimate in sulphate resistance specifications is also briefly discussed.

Keywords: *fly ash; specifications; sulphate attack; cement chemistry; R factor; concrete porosity.*

34. Halstead, W.J. "Quality control of highway concrete containing fly ash"; Sixth International Symposium on Fly Ash Utilization, Reno, Nevada, 1982, Vol. 2, pp. 394–407.

This paper discusses the probable causes of the limited use of fly ash in highway concretes from the standpoint of potential problems with quality control. The counteracting effects of the additional testing and control problems on the economic incentives for using fly ash to replace a portion of the portland cement are discussed. It is recommended that the use of fly ash meeting ASTM Specification C 618 be permitted at the option of a contractor, with approval of the mix design by the state.

Keywords: *highway concrete; quality control; fly ash; strength development; air-entrainment; loss on ignition.*

1982
International Symposium on the Use of PFA in Concrete University of Leeds, England, April 1982.
(Available from Dept. of Civil Engineering, University of Leeds, England.)

35. Owens, P.L., and Waddicor, M.J. "Techniques for the assessment and production control of pulverized fuel ash for use in concrete"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 51–59.

The authors have presented an overview of the techniques for quality control of fly ash for use in concrete in relation to the requirements of British standards. They suggest that, for a bituminous coal fly ash, the quality control parameters can be reduced to the monitoring of colour, loss on ignition, and fineness. In addition, moisture content, SO_3, and density affect the use of ash and require consideration. Methods of testing, frequency of testing, and significance of tests are discussed.

Keywords: *British standards; colour; density; fineness; fly ash; loss on ignition; moisture content; quality control; testing.*

36. Ellis, C. "The application of the two-point workability test and the British standard tests to OPC/PFA concretes"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 121–131.

The use of a two-point test based upon measurements of rheological parameters in fresh concrete is discussed. Comparisons are made with conventional slump, Vebe-time, and compacting factor tests for workability. The author concludes that fly ash enhances the workability of fresh concrete.

Keywords: *British standard; compaction; rheology; slump; workability.*

37. Ivanov, Ya., and Zacharieva, S. "Influence of fly ash on the rheology of fresh concrete"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 133–139.

The authors relate the rheological properties of fly ash concrete to a Bingham model. Data obtained by using vibro-viscometers are presented to show the effects of fly ash on workability. Fineness of the ash and the mixture-proportions used are reported to be the main determinants of the rheological characteristics of fresh fly ash concrete. Improved workability is said to result from the use of ash with high specific surface area.

Keywords: *fly ash; fresh concrete; mixture-proportions; rheology; specific surface; workability.*

38. Brown, J.H. "The strength and workability of concrete with PFA substitution"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 151–159.

The author reports an increase in workability when fly ash is substituted for cement such that for each 10 per cent by weight of ash in the mix, an increase in workability is obtained equivalent to that attained by adding 3 to 4 per cent of water. When ash is substituted for sand, workability was found to increase to an optimum level, when the ash present was at about 8 per cent by volume of aggregate. Above this level, workability decreased.

Keywords: *fly ash; strength; mixture-proportioning; workability.*

39. Banfill, P.F.G. "An experimental study of the effect of PFA on the rheology of fresh concrete and cement paste"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 161–171.

The author presents a general discussion of the application of a Bingham model to the rheology of fresh concrete and cement paste. He also discusses in some detail the equipment used to measure the rheological parameters of fresh concrete and the results of some experiments using fly ash concrete mixes. In general, it is concluded that fly ash causes a reduction in yield stress, but has little effect on the plastic viscosity of fresh concrete.

Keywords: *cement paste; fresh concrete; viscosity; rheology; workability; yield stress.*

40. Ong, L.T., Munday, J.G.L., and Dhir, R.K. "Mix design for OPC/PFA concrete"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 173–180.

The proportioning of fly ash concrete to attain 28-day strength equivalent to comparable plain concrete mixes is discussed. Strength–proportioning relationships are presented for typical concrete mixes.

Keywords: *fly ash; mixture-proportioning; strength.*

41. Brooks, J.J., Wainwright, P.J., and Cripwell, J.B. "Time-dependent properties of concrete containing pulverized fuel ash and a superplasticizer"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 209–220.

The authors present data on strength, elasticity, creep, and shrinkage for a range of concrete mixes incorporating both fly ash and superplasticizer. No significant adverse effects were observed from the use of fly ash. Creep of fly ash concrete was less than that for plain concrete.

Keywords: *creep; fly ash; elasticity; shrinkage; superplasticizer; time-dependent properties.*

42. Gifford, P.M., and Ward, M.A. "Results of laboratory tests on lean mass concrete utilizing PFA to a high level of cement replacement"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 221–230.

The use of high levels of fly ash is reported to decrease the rapid load strain capacity and modulus of rupture in lean concretes. Thermal expansion, creep, and autogenous volume change are reduced and drying shrinkage is increased.

Keywords: *creep; elastic properties; drying shrinkage; fly ash; laboratory tests; mass concrete; thermal expansion.*

43. Munday, J.G.L., Ong, L.T., Wong, L.B., and Dhir, R.K. "Load-independent movements in OPC/PFA concrete"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 243–254.

The authors report that volume changes in hardened concrete due to changes in moisture content and temperature are reduced when fly ash is used as a partial replacement for cement. No effects of practical significance were found to result from the use of fly ash with respect to drying shrinkage, wetting/drying expansion, or coefficient of thermal expansion.

Keywords: *drying shrinkage; fly ash; load-independent movements; temperature; thermal expansion.*

44. Yuan, R.L., and Cook, J.E. "Time-dependent deformation of high-strength fly ash concrete"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 255–260.

The use of a Class C fly ash as a partial replacement for cement in concrete is reported. It was concluded as follows:

- Normal, 60 MPa (28 days) concrete made with Type I portland cement and 20, 30, and 50 per cent of a Class C fly ash developed equivalent strength and modulus of elasticity to a reference concrete, at 28 days.
- Such concrete with 20 per cent ash had lower shrinkage and creep than reference concrete.
- With 30 or 50 per cent ash, slightly higher shrinkage and creep were noted.

Keywords: *Class C fly ash; creep; high-strength concrete; elasticity; shrinkage; time-dependent deformation.*

45. Dunstan, M.R.H. "The use of high fly ash content concrete in roads"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 277–288.

The use of high fly ash content roller-compacted concrete in road construction in Britain is discussed with presentation of some case histories.

Keywords: *fly ash; roller-compacted concrete; road construction; structural concrete.*

46. Blackie, A.D. "The influence of PFA on the properties of structural concrete"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 289–299.

The author presents a general overview of the properties of fly ash in structural concrete based on the experience of its use in Britain. Durability, structural parameters, and quality control are discussed and some consideration is given to sulphate resistance and alkali–aggregate reactivity.

Keywords: *alkali–aggregate reaction; fly ash; durability; quality control; structural concrete.*

47. Williams, J.T., and Owens, P.L. "The implications of a selected grade of United Kingdom pulverized fuel ash on engineering design and use in structural concrete"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 301–311.

The authors present a general review of the practical aspects of the use of fly ash in structural concrete. Selection and quality control of fly ash are considered, and the properties and durability of fresh and hardened fly ash concrete are discussed.

Keywords: *durability; fly ash; quality control; structural concrete.*

48. Woolley, G.R. "Construction of structures at Drax Power Station using PFA concrete"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 313–321.

A case study of the use of fly ash concrete is presented. Specifications, economics, and construction practices with fly ash concrete mixes are discussed.

Keywords: *case study; economics; fly ash; structural concrete.*

49. Copeland, B.G.T. "Concrete for hydraulic tunnels and shafts, Dinorwic Pumped Storage Scheme – Case History"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 323–342.

A case study of the use of fly ash concrete in tunnel structures is presented. Specifications, materials, quality control, and construction practices with fly ash concrete mixes are discussed.

Keywords: *case history; fly ash; hydraulic tunnels; quality control; shafts.*

50. Swamy, R.N. "Structural properties of fly ash concrete"; International Symposium on the use of PFA in Concrete, University of Leeds, England, 1982, pp. 343–355.

Some of the engineering properties of fly ash concrete are discussed, including mix design and results of tests conducted on concrete beams and slab-column connections. It is concluded that fly ash concrete can be satisfactorily designed to develop 1-day strengths equivalent to that of plain concrete. It is shown that structural members made from fly ash concrete exhibit satisfactory behaviour comparable with plain concrete.

Keywords: *concrete beams; engineering properties; fly ash; mixture-proportioning.*

1983

First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete Montebello, Canada, July-August, 1983

51. Mehta, P.K. "Pozzolanic and cementitious by-products as mineral admixtures for concrete – a critical review"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 1–46.

Since it is the mineralogical composition, and not the chemical composition, which would govern the pozzolanic and cementitious behaviour of a mineral admixture, this review treats the entire area of mineral admixtures as a unified discipline. Mineralogical and particle characteristics of major industrial by-products suitable for use as concrete admixtures are reviewed, especially in regard to relationships between physical and mineralogical properties of admixtures and performance characteristics of concrete. The latter include water demand, consistency, bleeding, workability, setting time, air-entrainment, temperature rise in fresh concrete, strength, modulus of elasticity, creep, drying shrinkage, sulphate resistance, alkali-silica reaction, and corrosion of steel in hardened concrete. Mechanisms by which the use of these by-products in concrete can improve engineering properties are discussed, and examples of data from field and laboratory investigations are given.

Keywords: *alkali–aggregate reaction; blast-furnace slag; concrete durability; fly ash; mineral admixtures; permeability; pozzolans; rice-husk ash; silica fume; sulphate resistance; thermal properties.*

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52. Lamond, J.F. "Twenty-five years' experience using fly ash in concrete"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 47–69.

This paper presents a review of the laboratory investigations and construction projects, using fly ash as partial cement supplement in concrete, carried out by U.S. Army Corps of Engineers. Investigations carried out on the effect of fly ash on properties of fresh as well as hardened concrete are discussed. The concrete properties of three massive concrete gravity dams built using fly ash concrete are reported. Cost savings per cubic yard of concrete has been the major benefit derived by the use of fly ash in concrete in these structures. The performance of these three dams with fly ash is comparable to other dams constructed of concrete without fly ash. Based on the above investigations, it is concluded that fly ash may replace portland cement up to 35 per cent by absolute volume in interior mass concrete, and 25 per cent by absolute volume in exterior mass concrete and in structural concrete.

Keywords: *bleeding; concrete durability; cost savings; cracking, erosion; flexural strength; fly ash; freeze–thaw durability; mass concrete; mix-proportioning; permeability; portland cement; spalling; temperature rise; workability.*

53. Sturrup, V.R., Hooton, R.D., and Clendenning, T.G. "Durability of fly ash concrete"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 71–86.

This paper presents a review of the research programs on fly ash concrete durability undertaken by Ontario Hydro, since the '50s. Major areas addressed have been: (1) thermal crack resistance in mass concrete, (2) reduction of alkali–aggregate reactivity, (3) freezing and thawing resistance, and (4) sulphate resistance. Data from field trials using fly ash concrete are also reported. Major findings of the research include:

- Fly ash is being used successfully in lieu of both CSA Types 20 and 40 (ASTM Types II and IV) moderate- and low-heat cements to control temperature rise and thermally induced cracking in mass concrete.

- The replacement of 25 per cent of normal portland cement with fly ash has been found to be effective in reducing alkali–silicate expansions.

- As long as adequate air contents are obtained, carbon content does not adversely affect the freezing and thawing resistance of concrete, at least within the 12 per cent CSA and ASTM limits. As long as carbon contents are established for each delivery of fly ash, dosages of air-entraining agents can be modified easily.

Keywords: *air-entrainment; alkali reactivity; alkali–silicate expansions; carbon; fly ash; freeze–thaw durability; mass concrete; pozzolan; sulphate resistance; thermal cracking; temperature rise.*

54. Yamato, T., and Sugita, H. "Shrinkage and creep of mass concrete containing fly ash"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 87–102.

This paper presents investigations on the effect of crushed sand and fly ash on the strength, elasticity, bleeding, shrinkage, and creep characteristics of mass concrete. Three types of cements and three types of fine aggregates, viz. seashore sand, crushed stone, and a blend of the two, were utilized for this study. The water-to-cement ratio by weight ranged from 0.40 to 0.50. All mixes were made at a slump of 10 cm (4 in.) and air content of 4 per cent.

- The blended cement concrete with fly ash showed the lowest shrinkage among the three cement concretes. The creep tests showed similar results.

- It is concluded that fly ash can be successfully included in some concretes to achieve good workability, high strength, and low shrinkage and creep. The poor workability, large shrinkage and creep of the crushed sand concrete can be improved by replacing a portion of the crushed sand with the seashore sand, or by replacement of a portion of the cement or the crushed sand by fly ash.

Keywords: *fly ash; mass concrete; shrinkage; creep; crushed stone; seashore sand; water-to-cement ratio; workability; compressive strength.*

55. Gebler, S., and Klieger, P. "Effect of fly ash on the air-void stability of concrete"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 103–142.

Concretes containing both portland cement and fly ash were evaluated to determine the effect of fly ash on air-void stability. Ten fly ashes with a wide range of chemical and physical properties as well as geographical origins were used.

Air contents of plastic concretes were determined, and both air content and air-void parameters were measured in hardened concretes cast at four time intervals after initial mixing. These tests indicate that air contents of concretes containing Class C fly ash appear to be more stable than those in concretes containing Class F fly ash. The higher the organic matter content of a fly ash, the higher will be the air-entraining admixture requirement, the greater is the air loss on extended mixing. Even though the air volume is reduced, the spacing factor, specific surface, and number of voids are little affected.

A "Foam Index" was determined for each of the ten fly ash–portland cement combinations. Air-entraining admixture requirements of actual concretes containing both portland cement and fly ash were compared to the "Foam Index" test results. These tests indicate that the "Foam Index" could be especially useful to concrete producers as a quality control test for checking the air-entraining admixture requirements for different sources of lots of fly ash.

Keywords: *admixtures; air-entraining agents; fly ash; Foam Index; air-void stability; loss on ignition; fresh concrete; hardened concrete.*

56. Samarin, A., Munn, R.L., and Ashby, J.B. "The use of fly ash in concrete – Australian experience"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 143–172.

The paper describes commercial use of concretes containing fly ash in Australia. Comparison is made between fly ash concrete and other concrete types, mainly on the basis of equal 28-day strength. Setting times, bleeding, workability, air-entrainment, rate of strength gain, elastic properties, flexural and indirect tensile strength, heat of hydration, shrinkage, creep, sulphate resistance, carbonation, abrasion resistance, alkali–aggregate reactivity are discussed. Field observations of concrete structures containing fly ash after prolonged environmental exposure are also included.

Keywords: *abrasion resistance; air entrainment; alkali–aggregate reaction; Australia; bleeding; carbonation; concrete; elastic properties; field observations; fly ash; heat of hydration; setting time; shrinkage; creep; strength gain; sulphate resistance; workability.*

57. Korac, V., and Ukraincik, V. "Studies into the use of fly ash in concrete for water dam structures"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 173–185.

The paper describes investigations undertaken to develop a suitable fly ash blended portland cement for concrete used in two large water dam projects in Yugoslavia, which have recently been completed. The fly ash selected for this purpose is produced at a power station using brown coal with combustion temperatures of 1550–1600°C, as compared to other Yugoslavian power stations using lignite coal with combustion temperatures generally in the range of 1000–1200°C. It is shown that the combustion temperature is the single most important factor in controlling the quality of fly ash, with excellent physical and pozzolanic properties being produced at higher temperatures. A fly ash content (F) of 50 per cent in portland cement (C), i.e., $F/(F + C) = 0.50$, was selected for these projects, as it was shown to be the most suitable blend with regard to the heat of hydration, setting time, consistency, and soundness properties. A concrete mix with 225 kg/m^3 of this fly ash–blended portland cement and aggregate of maximum size 63 mm (2 1/2 in.) was adopted, and both the laboratory and site tests showed this mix to possess good properties in the fresh and hardened states. A comparison of these results was made with the comparable concrete prepared with commercially available portland cement and slag cement, and the use of fly ash–blended portland cement was found to be advantageous.

Keywords: *blended cements; compressive strength; fly ash; heat of hydration; mass concrete; portland–pozzolan cements; setting (hardening); slag cements; temperature rise (in concrete).*

58. Manz, O.E. "Review of international specificiations for use of fly ash in portland cement concrete"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 187–200.

This paper presents a review of the various specifications, involving the use of fly ash in concrete, currently in use in the United States and other countries. In the United States, the classification of fly ash by reference to the type of coal has been questioned, as well as some of the specification limits. The many new "Western" fly ashes have caused concern for some properties not at present covered, such as free lime and sulphate resistance. Also, due to poor correlation between laboratory pozzolanic activity tests and field performance, there is a need for a system in terms of parameters controlling performance. The chemical and physical data for several fly ashes and some performance results involving the use of selected fly ashes in concrete are presented in this paper. A revised characterization scheme for fly ashes is discussed.

Keywords: *fly ash specifications; pozzolans; loss on ignition; autoclave expansion; sulphate resistance; free lime; fineness.*

Note: Another paper of similar contents has been published by the author in Proceedings of the Materials Research Society, Symposium N, 1981.

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59. Rossouw, E., and Kruger, J. "Review of specifications for additions for use in concrete"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 201–220.

Several countries have specifications for additions that are used in concrete, such as fly ash (pulverized fuel ash) or other pozzolans and vitreous blast-furnace slag, while other countries are preparing specificiations for such materials. This paper lists the more important existing specifications and summarizes, compares, and discusses their specific requirements. The differences and similarities of nomenclature, requirements, and methods of test are indicated. Attention is given to the relationship between the results obtained from a test and the material's performance in use. Specification test results may not always be a valid criteria for forecasting the performance of a material. A proposal is made for a more uniform system of nomenclature, specification, and testing for concrete additions.

Keywords: *admixtures; blast-furnace slag; fly ash; nomenclature; performance; pozzolans; review; specifications; standards; testing.*

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60. Munday, J.G.L., Ong, L.T., and Dhir, R.K. "Mix proportioning of concrete with PFA: A critical review"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 267–288.

Studies relating to proportioning of concrete incorporating pulverized fuel ash (PFA) as a partial replacement of cement (OPC/PFA concrete) are reviewed in this paper. Three different approaches are identified: simple replacement, modified replacement, and rational methods. Their implications are discussed, particularly the effects on the properties of resulting concrete, practical applications, and the optimum utilization of fly ash. It is suggested that OPC/PFA concrete should be designed without reference to control OPC concrete, and a mix design method is proposed for this purpose which is sufficiently simple for use in practice and is similar to the current practice for OPC concrete design. The authors hope that this may lead to the development of a more widely acceptable mix design method for OPC/PFA concrete.

Keywords: *admixtures; blended cements; fly ash; mixture-proportioning; water-to-cement ratio.*

61. Hobbs, D.W. "Influence of fly ash upon the workability and early-age strength of concrete"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 289–306.

The paper describes the workability and strength measurements made on concretes in which up to 20 per cent by weight of the aggregate was replaced by an equal volume of fly ash. This method of proportioning the concrete mix has the advantage that both the water–portland cement ratio and the volume of the water–portland cement fraction can be held constant so that the extent to which fly ash is inert or cementitious at early ages can be assessed. It is shown that the variations in slump are in broad agreement with the predictions for a Bingham suspension in which a proportion of the particles is replaced by an equal volume of finer particles and that the strength contribution attributed to the fly ash is dependent upon the water–portland cement ratio. Adjustment factors for water content, cement content, blended cement content, and aggregate content are calculated from the data presented, which enable concretes of similar workability and 28-day strength to the portland cement concrete to be formulated.

Keywords: *early-age strength; fly ash; mix proportioning; rheology; workability; Bingham suspension.*

62. Yuan, R.L., and Cook, J.E. "Study of a Class C fly ash concrete"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 307–319.

This paper describes an experimental investigation into the behaviour of fly-ash concrete with respect to strength, durability, shrinkage, and creep deformations. A sub-bituminous coal ash conforming to Class C requirements of ASTM C 618 was used. The use of fly ash as a partial replacement for cement ranged from 20 per cent to 50 per cent by weight of the cement. These studies confirm that (1) the rate of strength development of Class C fly ash concrete is comparable with that of portland cement concrete; (2) the effect of fly ash content on the shrinkage deformation is not as significant as the effect of water-to-cement ratio, (3) for a given water-to-cement ratio, creep deformation is influenced by the fly ash content, and (4) concrete with a fly ash content of 20 per cent replacement shows a better freeze–thaw durability than portland cement concrete.

Keywords: *Class C fly ash; creep properties; freeze–thaw durability; portland cement; compressive strength; drying shrinkage.*

63. Ho, D.W.S., and Lewis, R.K. "Carbonation of concrete incorporating fly ash or a chemical admixture"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 333–346.

This paper discusses the influence of the constituents and their proportions in concrete on the rate of carbonation of the concrete cover. Straight portland cement concrete and other concretes containing fly ash or a chemical water-reducing agent were investigated for the rate of carbonation.

Results have indicated that concretes having the same strength and water-to-cement ratio do not necessarily show the same rate of carbonation. For a strength level of 25 MPa, concrete containing fly ash carbonated 50 per cent faster than the straight portland cement concrete. Based on a common 28-day strength, concretes containing fly ash showed a significant improvement in quality when curing was extended from 7 to 90 days.

Keywords: *carbonation; chemical admixture; durability; fly ash; portland cement; water-reducing agent; accelerated tests; compressive strength; workability.*

64. Joshi, R.C., and Natt, G.S. "Roller compacted high fly ash concrete (geocrete)"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 347–366.

In this study, the use of sub-bituminous, Class C fly ashes from Alberta, a province in western Canada, for producing high fly ash roller-compactable concrete (geocrete) was investigated. Optimum moisture content and maximum density of each of the mixes containing sand and gravel as coarse and fine aggregates respectively, and mixtures of fly ash and cement, and fly ash and lime as cementitious materials were evaluated by geotechnical methods. Compaction and strength characteristics of the mixes containing various proportions of aggregate and cementitious material were evaluated in the laboratory. Durability characteristics and flexural strength of the selected mixes were also studied. The results indicate that the two sub-bituminous fly ashes from western Canada can be used to produce high fly ash concrete suitable for pavements and core of gravity dams.

Keywords: *blended cement; Class C fly ash; durability; flexural strength; geocrete; pavements; roller compaction; stabilization.*

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65. Buttler, F.G., Decter, M.H., and Smith, G.R. "Studies on the desiccation and carbonation of systems containing portland cement and fly ash"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 367–381.

In this study, cement/sand mortar cubes, some containing fly ash, have been subjected to a number of curing regimes involving desiccation and carbonation using a high partial pressure of carbon dioxide. The compressive strengths of the cubes were determined without fracturing them by applying an increasing axial load whilst the lateral strain on the cubes was monitored continuously. After the compressive strengths had been determined, the cubes were sectioned and each section analysed for calcium hydroxide and carbonate content.

The results show that, following curing at 20°C only and particularly when the pozzolanic reaction of the fly ash was restricted by desiccation, the cubes containing fly ash carbonated more readily than comparable ones in which fly ash was absent. With higher water contents and with non-desiccated cubes, those containing fly ash performed in a similar way to those that did not.

Keywords: *carbonation; desiccation; fly ash; mortars; portland cement; pozzolanic reaction.*

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66. Nasser, K.W., and Marzouk, H.M. "Properties of concrete made with sulphate-resisting cement and fly ash"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 383–395.

This investigation is a study of the structural properties of concrete made with sulphate-resisting cement (Type V) and Saskatchewan fly ash. Tests were performed on cylinders exposed to temperatures of 70° to 450°F (21.4° to 232°C) for periods of six months and over. The properties of strength, elasticity, creep, and creep recovery were studied for both sealed and unsealed specimens.

Test results revealed that temperature had minor effect on strength and stress–strain relationship for both sealed and unsealed specimens; however, the modulus of elasticity showed a continual decrease with a rise in temperature.

Creep of unsealed concrete increased with an increase in temperature up to 160°F (70°C) and decreased thereafter, while creep of sealed specimens decreased with a rise in temperature, except at 350°F (177°C) where it was one and a half times that at 70°F (21.4°C).

Keywords: *fly ash; sulphate-resisting cement; temperature effects; creep properties; creep recovery; compressive strength; modulus of elasticity.*

67. Bordonado, G., and Nissoux, J.L. "Road-building concretes incorporating fly-ash or slag"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 471–493.

This paper describes the studies carried out in order to make better use of the binding properties of fly ash and slag to develop very economical rigid pavements with low energy content. Experimental motorways were built with concretes incorporating fly ash or slag as 30 per cent replacement of cement. The paper describes how the characteristics of these concretes were worked out, how they were obtained and applied throughout the implementation of the project, how systems of control were adapted and what difficulties were encountered. The possibilities of developing compacted concrete incorporating fly ash for rigid pavements are also discussed.

Keywords: *fly ash; blast-furnace slag; compacted concrete; rigid pavements; portland–pozzolan cement; portland–slag cements.*

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68. Mailvaganam, N.P., Bhagrath, R.S., and Shaw, K.L. "Effects of admixtures on portland cement concretes incorporating blast-furnace slag and fly ash"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 519–537.

This study investigates the effects of conventional chloride, non-chloride, and superplasticizer admixtures on concretes in which 30 per cent by weight of the cement has been replaced by slag or fly ash. Two series of mixes utilizing different admixture dosages and two curing temperatures (22°C and 5°C) were investigated. The compressive strength results and temperature time curves indicate that at 22°C all three admixtures were effective in off-setting the early-age strength reduction due to cement replacement. With the exception of fly ash mixes, 28-day strengths were close to and in some instances exceeded the strength of the 100 per cent portland cement mixes. At lower temperatures (5°C) the performance of conventional accelerating admixtures was marginal in comparison with the superplasticizer. In general, admixture effectiveness observed in both series of mixes was in the order: superplasticizer > chloride > non-chloride.

Keywords: *accelerators; admixtures; blast-furnace slag; fly ash; portland cement; setting; strength; superplasticizer; temperature.*

69. Warris, B. "Strength of concrete containing secondary cementing materials"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 539–557.

The paper describes a model for the calculation of the strength of concrete with secondary materials. The model is based upon the type of correlation between strength and water-to-cement ratio (or water + air-to-cement ratio) originally suggested by Feret and later modified by Bolomey. An important additional parameter is introduced, viz.:

E_r = efficiency function, describing the influence of the secondary material on the concrete strength.

The variation of E_r has been studied by means of experiments dealing with the binding of CaO or with the strength of concrete containing fly ash or silica fume. The study leads to a formula for strength:

$$f_c = K_B (1 + \Phi \{p_r\}) \left(\frac{C}{W + A} - k_B \right)$$

where $\Phi\{p_r\} = k_n p_r$ for fly ash

$\Phi\{p_r\} = 1 - (1 - p_r)^n$ for silica fume

p_r is the relative quantity of secondary material, and
k_n and n are characteristics of its binding capacity.

The formulae have been verified by means of a great number of test results, mainly from France and Scandinavia. The paper contributes to a balanced technical evaluation of secondary materials and to rational mix design.

Keywords: *compressive strength; concretes; fly ash; portland–pozzolan cements; silica fume; water-to-cement ratio.*

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70. Swamy, R.N., Ali, S.A.R., and Theodorakopoulos, D.D. "Engineering properties of concrete composite materials incorporating fly ash and steel fibres"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 559–588.

Three major factors, namely, environment protection, energy savings, and inherent technical advantages, demand that fly ash of controlled quality and composition be incorporated in all concrete construction. This paper shows that concrete of structural quality, containing fly ash, steel fibres, normal weight or lightweight aggregates, and a plasticizing/water-reducing admixture or a superplasticizer can be designed to produce cohesive and workable mixes that enable easy transportation, pumping, compaction, and finishing of the material. It is also shown that such mixes can be easily and satisfactorily vibrated into place in structural members with bar reinforcement and thin sections. Mixes designed by partial but direct replacement of 30 per cent by weight of cement can have early-age strength and elasticity properties comparable to that of concrete without fly ash, and exhibit structural behaviour similar to normal concrete. Extensive data are presented to demonstrate the applicability of these materials in practice.

Keywords: *compaction; early-age strength; elasticity; finishing; fly ash; lightweight aggregates; plasticizing; pumping; steel fibres; superplasticizer; water-reducing admixture; workability.*

71. Carette, G.G., and Malhotra, V.M. "Early-age strength development of concrete incorporating fly ash and silica fume"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 765–784.

Early-age strength development of concrete in which part of the portland cement has been replaced by low-calcium fly ash tends to be slow, because fly ash acts as a relatively inert component during this period of hydration, though at later ages it contributes significantly to strength development. It was considered that the problem of low early-age strength of portland cement–fly ash concrete could be overcome by the incorporation of small amounts of condensed silica fume, a very fine and more rapidly reactive pozzolan.

This report presents the results of an investigation on the early-age strength development of concrete incorporating 30 per cent low-calcium fly ash, to which small amounts of condensed silica fume have been added. The amounts of the fume ranged from 0 to 20 per cent by combined weight of the portland cement plus fly ash. A total of thirty 0.06-m^3 concrete mixtures with water-to-(cement + fly ash) ratios ranging from 0.40 to 0.80 were made; 240 cylinders were tested in compression and 180 prisms were tested in flexure. A supplementary series of six concrete mixtures was made to determine the effect of silica fume and fly ash on the long-term strength development of concrete.

Test data showed that the incorporation of condensed silica fume increased the compressive strength of concrete at all ages as compared with the compressive strength of the control concrete (70 per cent portland cement + 30 per cent fly ash). At 7 days, the loss of compressive strength due to the partial replacement of cement by fly ash was completely overcome by the addition of 10 per cent condensed silica fume for concretes with water-to- (cement + fly ash) ratios ranging from 0.40 to 0.60; 15 to 20 per cent was required for concretes with higher water-(cement and fly ash) ratio. At 28 days, regardless of the water-to-(cement and fly ash) ratio, the effect was generally achieved with less that 5 per cent silica fume addition. The later-age strength development of portland cement–fly ash concrete did not appear to be impaired by the use of condensed silica fume indicating availablity of sufficient lime for the fly ash pozzolanic activity.

Keywords: *age-strength relations; fly ash; plasticizer; portland cement; pozzolan; silica fume; strength.*

72. Virtanen, J. "Freeze-thaw resistance of concrete containing blast-furnace slag, fly ash or condensed silica fume"; First CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-products in Concrete, Montebello, Canada, 1983, pp. 923–942.

The durability of concrete to freezing and thawing is examined in this study. Air-entrained and non-air-entrained concretes incorporating fly ash, slag, and condensed silica fume were tested and the following properties were determined: compressive strength, protective pore ratio, freezing expansion, critical degree of saturation, and optical analysis of the pore structure. The test results indicate that condensed silica fume and blast-furnace slag additions improve the freeze–thaw resistance of concrete slightly when the strength and air content are kept constant. The use of supplementary materials decreases the freeze–thaw resistance of concrete if the air-entraining agent dosage is not increased.

Keywords: *freeze–thaw durability; air-entrainment; blast-furnace slag; fly ash; condensed silica fume; pore ratio; freezing expansion; critical degree of saturation.*

1984
AshTech'84: Second International Conference on Ash Technology and Marketing
London, England, September 1984

73. Bamforth, P.B. "Heat of hydration of PFA concrete and its effect on strength development"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 287–294.

This paper presents results of tests carried out to quantify the effect of reduced heat of hydration and the consequent reduction in temperature rise resulting from partial replacement of cement by pulverized fuel ash (PFA) in concrete. Adiabatic temperature rise is measured in concretes with a range of cement contents, mix temperatures, and levels of PFA. The influence of early-age temperature rise on the strength development is determined. The author concludes that it may be possible to use lower total cement contents for PFA concretes than for OPC concretes, whilst achieving comparable in-situ strength.

Keywords: *pulverized fuel ash (PFA); heat of hydration; adiabatic temperature rise; heat cycling.*

74. Browne, R.D. "Ash concrete – its engineering performance"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 295–301.

The potential technical advantages and deficiencies of PFA concrete over OPC concrete in relation to engineering performance and durability are reviewed. The author draws attention to the need for more work in areas of uncertainty such as the effect of curing in ash concrete. The importance of a more co-ordinated approach to research in the use of ash concrete with relevance to the in-situ conditions of the structure in service, and laboratory tests simulating current site practice are emphasized.

Keywords: *fly ash concrete; heat of hydration; early-age strength gain; long-term strength; stiffness; permeability; corrosion of reinforcement; carbonation; alkali–silica reaction; freeze–thaw resistance; sulphate attack.*

75. Cabrera, J.G., Woolley, G.R., Hopkins, C.J., Lee, R.E., Plowman, C., and Fox, H. "The relevance of pulverized fuel ash properties on the strength of concrete"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 303–312.

Two-year data accumulated on the physical, chemical, and mineralogical properties of eight different British pulverized fuel ashes are analysed in order to characterize the ashes and evaluate their variability. The strength properties of PFA concretes containing 30 per cent by weight of PFA are also evaluated. Large variations are found in the physical and chemical characteristics of the PFAs, whereas the resulting concrete strength properties are consistent. Statistical evaluation of the data indicates that concrete with appropriate properties can be made incorporating any one of the ashes studied.

Keywords: *pulverized fuel ash (PFA); physical properties; chemical composition; strength properties.*

76. Cripwell, J.B., Brooks, J.J., and Wainwright, P.J. "Time-dependent properties of concrete containing pulverized fuel ash and a superplasticizer"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 313–320.

This paper presents results of tests carried out to compare the values of strength, elasticity, creep, shrinkage, and swelling at various ages over a period of 300 days in OPC concrete and OPC/PFA concrete with and without a superplasticizer. The incorporation of PFA and superplasticizer is found to produce a concrete which has higher strength at both early and later ages than OPC concretes of similar workability. The superplasticizer improves the early-age strength development of OPC/PFA concrete without losing the benefit of later development of strength associated with the pozzolanic activity of PFA. Similar, but smaller, trends are observed for indirect tensile strength and modulus of elasticity. The combined influence of PFA and superplasticizer gives the greatest reduction in shrinkage and creep compared to that of OPC concrete, whereas the slower rate of hydration of the OPC/PFA concrete results in slightly more swelling due to adsorption of water. It is concluded that the beneficial effects of high-early strength and long-term strength coupled with low-shrinkage and creep in an OPC/PFA concrete with superplasticizer would be advantageous in pre-stressed concrete structural applications.

Keywords: *pulverized fuel ash (PFA); superplasticizer; pozzolanic activity; strength; elasticity; creep; shrinkage; swelling.*

77. Ellis, C. "Some aspects of strength and related 'in situ' properties of air-cured and moist-cured OPC/PFA concretes"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 321–328.

This paper analyses the relationships between compressive strength, indirect tensile strength, and pulse velocity for standard moist-cured OPC/PFA concrete specimens, and provides estimates of concrete strength from calibration functions and in situ test data for moist and air-cured specimens. Compressive strength, indirect tensile strength and pulse velocity tests are made on concrete specimens such as cubes, cylinders, prisms and model structure slabs made from three OPC/PFA mixes, and cured under moist and air-curing conditions. The results indicate that functions delating certain strength and pulse velocity test parameters for OPC concretes are similar to those obtained for OPC/PFA concretes. In addition, strength estimates using combined strength/pulse velocity measurements and calibration data on OPC/PFA standard moist-cured cubes and air-cured model structural slabs are found to be comparable with those obtained from extracted cores.

Keywords: *ordinary portland cement/pulverized fuel ash (OPC/PFA) concrete; compressive strength; indirect tensile strength; pulse velocity; moist-curing; air-curing; calibration functions.*

78. Dhir, R.K., Munday, J.G.L., and Hubbard, F.H. "PFA for concrete: an engineering judgement"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 329–341.

From the extensive studies done over a period of eight years at Dundee University, U.K., a number of guidelines are presented in this paper regarding the use of PFA in concrete. It is demonstrated that most of the ashes produced in the U.K. can be used as pozzolans in concrete without any detrimental effect. The inherent inability of the standard tests employed to measure the pozzolanicity of PFA is identified. The limits specified in the British standard for fineness and water requirement for PFA in concrete are shown to be unfounded, and changes to these specifications are proposed. A direct procedure for mix-proportioning concrete with any PFA, without reference to conventional concrete, is outlined. Concrete with PFA, when designed for the usually specified properties, is shown to develop at least comparable engineering properties to OPC concrete. The need for more pragmatic research on several aspects in the use of PFA in concrete, particularly on the durability of concrete, is emphasized.

Keywords: *pulverized fuel ash (PFA); pozzolanic action; PFA variability; mix-proportioning; elastic and creep deformation; drying shrinkage; thermal expansion; durability.*

79. Hums, I.D., Huber, H., München, Y.A., and Mörtel, H. "Influence of different fly ashes on the properties of aerated lightweight concrete"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 343–350.

The purpose of this study is to clarify the effects of two different fly ashes on the various properties of aerated lightweight concrete. Aerated lightweight concrete is produced with varying contents of (i) brown coal fly ash with 50 per cent SiO_2 and very low carbon content, and (ii) hard coal fly ash with 38 per cent SiO_2 and high carbon content. The addition of these two ashes results in up to 33 per cent and 43 per cent losses in compressive strength of concrete with brown coal fly ash and hard coal fly ash respectively, when compared with the standard grade. Shrinkage and thermal conductivity are found to be reduced by the addition of fly ashes, by varying degrees for each fly ash. It is shown that the different constituents of the two fly ashes such as Al_2O_3 and carbon content on one hand, and the new formation of minerals within the concrete on the other, are responsible for the variable effects on strength, shrinkage, and thermal conductivity. The study indicates that the use of fly ashes for aerated lightweight concrete production has negative effect on the strength from the construction-related physical properties point of view, but positive effects on the shrinkage and thermal conductivity.

Keywords: *aerated lightweight concrete; brown coal fly ash; hard coal fly ash; thermal analysis; X-ray methods; thermal conductivity; shrinkage; compressive strength.*

80. Marzouk, H., and Nasser, K.W. "The effect of age of loading on estimating creep of mass concrete containing fly ash and exposed to high temperature"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 351–358.

The authors present a method for estimating the effect of age of loading on the creep of mass concrete containing fly ash and exposed to high temperatures. In this method creep is assumed to be made of two components: (i) standard creep, which is considered to be the creep of an ideal concrete whose strength does not change with time, and (ii) correcting creep, which is due to the change in stress–strength ratio with time. The creep of mass concrete exposed to high temperatures is estimated by superimposing standard creep and correcting creep. The proposed method is verified experimentally using concrete specimens incorporating fly ash at temperatures of 71°C, 149°C, and 232°C and at ages of 7, 14, 28, and 56 days, and the results are found to be in good agreement with the calculated values. It is concluded that though this method is quite extensive, it is the most suitable for this special problem, since other available methods produce large errors in creep.

Keywords: *creep; mass concrete; high temperature effects; standard creep; correcting creep.*

81. Swamy, R.N. "Fly ash utilization in concrete construction"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 359–367.

This paper discusses three areas of fly ash utilization in concrete construction: (i) as partial replacement of cement, (ii) as coarse aggregate obtained by sintering fly ash, and (iii) as a filler. Thirty per cent direct replacement by weight of cement is recommended as a simple, feasible, and practical method of producing concretes with material and structural properties almost identical to those of concrete of similar strength without fly ash. A much higher replacement of 50 to 70 per cent by weight is indicated yielding sound technical advantages in thin-section constructions such as permanent formwork, thin-sheet asbestos replacements, ferrocement construction, boat construction, and sprayed concrete. The paper recommends the use of aggregates manufactured from PFA in concrete, and presents extensive data on the material properties and structural performance of such concrete. The use of fly ash as a filler for special concretes such as sulphur concrete is also discussed. It is suggested that all concrete of the future should be fly ash concrete — as a rule, not as an exception.

Keywords: *pulverized fuel ash (PFA); partial replacement of cement; fly ash aggregates; filler; sulphur concrete; concrete thin sections.*

82. Nagataki, S. and Ohga, H. "The application of fly ash to high strength concrete products"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 369–376.

This study investigates the influences of curing conditions on the mechanical properties and creep characteristics of concrete with a large quantity of fly ash contained as a cement replacement, in order to study the applicability of fly ash to high-strength concrete products. It is found possible to increase compressive strength upon steam-curing by increasing maturity through increasing curing time and temperature. Upon autoclave-curing, compressive strength is subject to the influence of curing temperature, and strength gain properties are found to be favorable at a curing temperature of 190°C. Autoclaved concrete with 40 per cent of cement replaced by fly ash is found to be effective with regard to both compressive strength and creep. Actual pre-stressed concrete piles are manufactured based on the results of the above investigations, and 40 per cent replacement of cement by fly ash is found to be practical if the piles are to be subjected to autoclave-curing.

Keywords: *high-strength concrete; mechanical properties; creep; steam-curing; autoclave-curing; maturity; pre-stressed concrete piles.*

83. Day, R.L., Joshi, R.C., Langan, B.W., and Ward, M.A. "Examination of the use of high proportions of high-lime content fly ash in construction"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 377–385.

This paper presents a general overview of a research program under way on the use of western Canadian high-lime fly ash in concrete. The general aim is to study the relationship between fundamental aspects (such as microstructural and chemical changes and specific ash characteristics) and their influence on the engineering performance of fly ash concrete (strength, permeability development, and durability in particular). The areas of research include: (i) strength development of concrete containing various proportions and types of fly ash, (ii) durability of concrete containing fly ash, (iii) influence of the $+45\ \mu m$ size fraction on strength and durability, (iv) use of high proportions of high-lime fly ashes in fly ash stabilized aggregate (geocrete), (v) classification of fly ash, and (vi) chemistry and microstructure of fly ash pastes. To illustrate the nature of investigations, recently obtained experimental results are presented. The behaviour of the western Canadian high-lime fly ashes is compared and contrasted to typical eastern North American ashes and a typical British ash.

Keywords: *high-lime fly ash; sub-bituminous coal; lignitic coal; strength of fly ash concrete; durability of fly ash concrete; geocrete; curing temperature; microstructural analysis.*

84. Albala, J.A.L. and Rossello, S.A. "Concrete impermeability study"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 387–389.

A test method capable of quantifying the impermeability of concretes accurately is presented in this paper. The methodology and the apparatus for measuring impermeability are described. A comparative study is made of the impermeability of concretes with various types of cement — for equal strengths, slumps, and maximum quantity of dry materials. In addition, the impermeability of concretes with a Spanish fly ash (Cercs) is investigated. The authors conclude that, with the remaining characteristics such as type of cement and consistency being the same, dry concretes are found to be the most impermeable, and concretes made with Cercs fly ash are found to be more impermeable than any other type of concrete tested.

Keywords: *impermeability of concrete; apparatus for measuring impermeability; Cercs fly ash; Abrams cone; aggregate composition curve.*

85. Hopkins, C.J., and Cabrera, J.G. "The influence of pulverized fuel ash on the workability of concrete"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 393–398.

Contrary to the general belief that pulverized fuel ash (PFA) enhances the workability of concrete, the workability may increase or decrease when PFA is used in concrete, depending on the properties of ash used. This paper proposes a simple method to characterize PFAs in relation to their ability to increase workability. A parameter "shape factor," which is a comparison of measured specific surface area of the fly ash and the calculated specific surface area derived from the particle size distribution of the fly ash, is proposed. The workability of PFA concretes is assessed using a modified Tattersall two-point test apparatus. A laboratory study involving seven different PFAs shows that the shape factor influences the effect of PFAs on concrete workability. The proposed shape factor parameter provides a quick and easy method of assessing PFAs prior to their use in concrete.

Keywords: *pulverized fuel ash (PFA); workability; measured specific surface area; calculated specific surface area; shape factor; Tattersall two-point test; Abrams law.*

86. Howell, L.H. "PFA/cement normal site concrete – a detailed 25 year old report"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 399–401.

The author reviews a report he prepared 27 years ago on typical site construction concrete. The construction was of a transmission substation where the foundation concrete comprised 20 per cent replacement of cement by pulverized fuel ash. The construction practices, tests conducted, and observations made on the above concrete are detailed in the present paper. Recently, cores were taken from this concrete and analysed with sophisticated equipment. A report on this investigation is to be published.

Keywords: *pulverized fuel ash concrete; cores; workability; compressive strength; blended cements.*

87. Munn, R.L. "Long term field behavior of fly ash concretes"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 403–409.

This paper reports results of field surveys and laboratory analyses carried out on fly ash concrete structures and trial pavements to observe properties such as compressive strength, carbonation, and absorption. Several case histories which include both visual inspection and analysis of cores taken from structures are reported. First-hand comparisons between the long-term properties of fly ash concrete and that of other concretes are made possible by this investigation. The results indicate that when the fly ash concrete is proportioned to meet service requirements and is effectively cured, it performs as well as, if not better than, other types of concrete proportioned on the basis of equal 28-day strength and slump.

Keywords: *fly ash concrete; durability; compressive strength; carbonation; absorption; abrasion resistance; long-term field behaviour.*

88. Richards, R.G. "The use of pulverized fuel ash in the construction of a nuclear power station"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 411–415.

This paper reviews the use of pulverized fuel ash (PFA) as cement replacement adopted in the construction of a nuclear power station. The details of the concrete batching complex and the effects of PFA on the concrete developed are described. In addition, the use of PFA in the design of special concrete mixes utilized in the various structures is discussed. Some important aspects to be considered in the use of fly ash concrete such as commercial advantages, slower strength development, effects of excess carbon, and flexibility in the use of materials are discussed.

Keywords: *pulverized fuel ash (PFA); cementitious materials; pumpability, strength development; excess carbon; flowing concrete; prestressed concrete.*

89. Woolley, G.R. "Major construction using PFA concrete at Drax"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 417–435.

This paper describes the construction of various structures of a power station at Drax, U.K., using pulverized fuel ash (PFA) concrete. Only the cooling tower shells of Drax Power Station completion works do not contain PFA as cement replacement in concrete. Pre-cast, pre-stressed end-bearing piles were manufactured using PFA concrete, and the compressive strength and modulus of elasticity results obtained suggest that the material is well suited to this demanding role. The details of pre-cast pile construction, storage, and testing are presented. Examination of PFA concrete cores from other structures shows a high standard of durability and an increasing gain in strength. The records illustrate the versatility and acceptability of PFA as partial replacement of cement in structural concrete.

Keywords: *pulverized fuel ash (PFA); cement replacement; prestressed end bearing piles; concrete mix design; foundations; ancillary structures; cooled concrete.*

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90. Plowman, C. "The chemistry of PFA in concrete – a review of current knowledge"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 437–443.

This paper presents a review of current knowledge on the chemical reactions involving PFA occurring in cement-based systems. The way in which the physical and chemical effects influence one another and the properties of cement paste is discussed. The areas of discussion include: (i) chemical and mineralogical analysis of PFAs, (ii) reactions of PFA in concrete, (iii) influence of PFA chemistry on concrete strength properties, (iv) influence of PFA chemistry on concrete durability. The study indicates that it is now largely possible to explain not only the increase in long-term strength which results from incorporating PFA in a concrete mix, but also other properties of engineering significance.

Keywords: *pulverized fuel ash (PFA); chemical and mineralogical constituents of PFA; X-ray diffraction; pozzolanic reaction; early-age strength; long-term strength; porosity; sulphate attack; alkali–silica reactivity; carbonation and reinforcement protection.*

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91. Munn, R.L. "Fly ash in rolled concrete pavement and slipformed applications"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 455–460.

This paper describes the application of fly ash concrete to Australian road construction in recent years. During the short time that slipform paving equipment and rolled concrete pavement technology have been used in Australia, fly ash concrete has played an important role in the successful development of these placing methods. The benefits derived by the incorporation of fly ash in concretes for the above applications are discussed. Typical properties of concretes suitable for both applications are provided. Concretes containing fly ash levels of up to 75 per cent have proved invaluable to meet the conflicting engineering requirements of low compressive strength, high tensile strain capacity, good compaction, and low drying shrinkage. These fly ash concretes are found not only to meet the performance criteria, but generally provide some additional benefits.

Keywords: *rigid pavements; flexible pavements; rolled concrete pavements; slipformed concrete pavements; fly ash concrete properties.*

92. Proctor, R.T., and Lacey, R.A.C. "The development of high fly ash content concrete at Didcot Power Station"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 461–467.

This paper outlines the work undertaken at Didcot Power Station of the Central Electricity Generating Board, U.K., in the development of high fly ash content concrete (HFCC). HFCC was used as pavement quality concrete in the construction of roadways to take heavy tracked vehicles and coalmoving plant, and later in the construction of an oil tank foundation and a bund for containing spillage in the event of a tank failure. A comprehensive testing program was undertaken to provide data on the long-term performance of the materials, including cores taken from the placements at various times and tested for comparison against the cube strengths. Highly satisfactory results were obtained from these programs. After the successful completion of the above projects, further constructions have been undertaken using HFCC. It is accepted that good-quality concrete, with a slight cost advantage over OPC concrete, can be obtained by incorporating 30 per cent fly ash. However, after the experience gained in the development work at Didcot, the authors conclude that a cementitious content with up to 50 per cent fly ash by design can produce durable, resistant, high-quality, high-strength concrete with considerable cost saving.

Keywords: *high fly ash content concrete (HFCC); pavement quality concrete; cube compressive strength; flexural strength; high workability.*

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93. Butler, J.E. "The penetration of concrete containing high proportions of fly ash"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 475–482.

The objectives of this investigation are to develop a procedure for the rapid measurement of concrete permeability and to compare the permeability values of the laboratory-made specimens and cores extracted from existing structures. The effect of using high proportions of fly ash in concrete, and the influence of water-to-cement ratio, cement content, and time on permeability of concrete are also studied. The application of Darcy's Law of permeability to concrete is discussed and the test method is based on this law. The tests on mature specimens indicate that high fly ash concrete has permeability similar to that of conventional concrete. The permeability of core specimens is found to be high when compared to that of cast specimens. The study indicates that the permeability of concrete is, by no means, uniform. It is concluded that while the application of Darcy's Law to concrete is convenient, the material does not comply with that rule.

Keywords: *permeability of concrete; Darcy's Law; coefficient of permeability; penetration tests; high fly ash concrete.*

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94. Boas, E.A., and Spanjer, J.J. "The manufacture and the use of artificial aggregates from fly ash produced according to the Dutch cold bonded 'Aardelite' process"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 577–582.

The hydrothermal and cold-bonded processes of fly ash aggregate production were developed with the aim to produce these aggregates at a lower cost than those produced by sintering processes. This paper presents a new process for the production of cold-bonded fly ash aggregates called the "Aardelite" process developed by the Dutch firm Aarding BV. The process is described in detail, and the market analysis and the economic advantages of this aggregate are presented. The production process is said to be environment "friendly," with low energy consumption and is free of emissions. The authors conclude that through the production of "Aardelite" aggregates, the ash disposal problems of the power stations can be solved satisfactorily, at a cost which is generally far below that of any new disposal system.

Keywords: *fly ash aggregates; sintering process; hydrothermal process; cold bonded process; "Aardelite" process; middle class concrete.*

95. Ogden, C., and Riches, M.E.A. "A review of the Lytag process and its role in 'Total Ash Management'"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 583–588.

The Lytag process is a method of using large volumes of fly ash for the manufacture of sintered lightweight aggregate. This paper explains the role of the Lytag process in the concept of power station "ash management" marketed by Pozzolanic Lytag Limited, U.K. The currently marketed products consist of: (i) the very fine, low carbon fraction of fly ash used as a cementitious component of structural concrete, (ii) fly ash of medium fineness used in the manufacture of sintered lightweight aggregate marketed as Lytag, (iii) the coarser fractions of fly ash mixed with OPC, water, and additives to produce stabilized fills and grouts, and (iv) the furnace bottom ash, marketed as a lightweight aggregate, and mixed with Lytag finished products for use in high-quality masonry units. The paper describes Lytag applications ranging from the inclusion in structural/pre-cast concrete, floor and roof screeds, no fines structural fills, aggregate blocks, refractory, pipe surround/bedding, land drainage, aquatic filter media, horticulture, agrochemicals, and vehicle arresters.

Keywords: *Lytag process; pozzolan; stabilized fills and grouts; low density; high strength; low shrinkage; insulating characteristics; "total ash management".*

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96. Follett, P.M. "Sintered PFA concrete as used from composite construction in the United Kingdom"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 589–595.

Composite floors and beams using concrete containing sintered pulverized fuel ash (SPFA) are becoming important in a new generation of efficient steel structures. This paper describes the application of SPFA concrete to steel-framed structures, when floors and/or beams utilize composite construction. The mix constituents, density, fire resistance, and commercial aspects of SPFA concrete are described. The recent developments in SPFA concrete applications in the U.K., and four major projects where this technology has been employed are detailed.

Keywords: *sintered pulverized fuel ash (SPFA); composite structures; mix constituents; density; fire resistance; steel decking; shear studs; structural design; construction.*

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97. Shotter, J. "Sintered PFA in masonry units"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 597–590.

Lytag is a man-made aggregate manufactured by Pozzolanic Lytag Limited, U.K., made through sintering pulverized fuel ash (PFA) under carefully controlled conditions. This aggregate offers a range of coarse and fine material of consistent size and quality. The masonry units produced with sintered PFA aggregates provide a wide variety of products in different sizes, textures, and strengths, suitable for most applications. This paper discusses the composition and grading of Lytag aggregates, the equipment and procedure used in the manufacture of pre-cast sintered PFA masonry units, the strength properties, and other cost benefits obtained from Lytag masonry blocks.

Keywords: *sintered pulverized fuel ash aggregates; pre-cast masonry units; bulk density; insulating properties; manufacturing units; compressive strength; cost benefits.*

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98. Jones, P.K. "A review of an overseas Lytag project"; AshTech '84: Second International Conference on Ash Technology and Marketing, London, 1984, pp. 603–611.

This paper reviews a Lytag aggregate project carried out for one of the Netherlands public utilities (PGEM) to solve the fly ash disposal problem of a coal-burning power station. The history of the generating station at Nijmegen, Netherlands, the fly ash disposal problem experienced by the utility, the feasibility study of a Lytag project to utilize the fly ash, and the successful implementation of a Lytag aggregate plant are described in detail.

Keywords: *Lytag process; fly ash disposal; PGEM program evaluation; Lytag aggregate plant; environmental aspects.*

1984

The Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal I
Materials Research Society, Boston, USA, November 1984

99. Roy, D.M., Luke, K., and Diamond, S. "Characterization of fly ash and its reactions in concrete"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal I; Materials Research Society, Boston, 1984, pp. 3–20.

The currently produced fly ashes differ much more widely from each other in composition and other characteristics than the earlier fly ashes, owing to the widespread use of low-rank sub-bituminous and lignitic coals. The current ASTM classifications into Class F and Class C pozzolan categories are not adequate to describe all their important properties. This paper provides an analysis of the results of recent investigations on fly ash characterization and its relevance to performance of fly ash in concrete. Current characterization methods are reviewed, including physical characterization by particle size distribution, shape, apparent specific gravity, content of hollow grains and of residual coal fragments, chemical procedures of various kinds, and SEM, EDXA, XRD, and other methods for the determination of mineralogical content and glass character. Etching and chemical dissolution procedures are considered to be particularly important. The state of these various methods, current results of their use in fly ash characterizations, and their relations to reactivity and performance of fly ashes in cement and concrete are discussed.

Keywords: *fly ash characterization; morphology; composition; mineralogy; cenospheres; plerospheres; scanning electron microscopy; X-ray diffraction; high-calcium fly ash; low-calcium fly ash; etching and chemical dissolution techniques; fly ash classification.*

100. Grutzeck, M.W., Fajun, W., and Roy, D.M. "Retardation effects in the hydration of cement–fly ash pastes"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal I; Materials Research Society, Boston, 1984, pp. 65–72.

This paper presents an investigation on the hydration of high-calcium and low-calcium fly ash–cement mixtures, carried out to determine the effect of fly ash upon the hydration of a Type I portland cement, and the associated mechanisms of hydration. Chemical data are presented showing the effects of fly ash upon portland cement solution chemistry. The cement and fly ash–cement blends in question, formulated with a water-to-solid ratio of 10/1, are allowed to hydrate in sealed plastic bottles at 38°C, and the concentrations of ions in solution are determined with an SMI III DC plasma atomic emission spectrophotometer and a Dionex Model 2000 ion chromatograph.

Analyses of solution compositions and calorimetric measurements are made. When blended with portland cement, both fly ashes retard the early hydration process, the high-Ca more so than the low-Ca. The retardation and hydration effects are discussed in terms of solution composition data and solid-phase characterization. The hydration effects are interpreted and compared with the results of previous work.

Keywords: *cement–fly ash pastes; high-calcium fly ash; low-calcium fly ash; hydration; bottle-hydration studies; solution compositions; thermogravimetric analysis; ettringite formation; chemisorption.*

101. Baker, M.D., and Laguros, J.G. "Reaction products in fly ash concrete"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal I; Materials Research Society, Boston, 1984, pp. 73–83.

This study evaluates the differences between the reaction products of portland cement concrete and fly ash concrete in which fly ash is used as a partial replacement for portland cement. The role of chemical composition and crystalline structure of the reaction products in the compressive strength of concrete is emphasized. A number of standard tests are conducted on Class C high-lime fly ash concretes to determine the compressive strength, setting time, slump, air content, and unit weight. In addition, a simple test for measuring the heat of hydration of pastes is developed. X-ray diffraction (XRD) and scanning electron microscopy (SEM) are employed to help interpret the results of these tests, and determine the chemical composition of reaction products. Setting time and early compressive strength are adversely affected by the addition of fly ash. However, beyond one week, all the fly ash concrete mixes gained strength at a faster rate than the corresponding control mixes. The retardation mechanism is considered to be associated with the formation of high levels of ettringite early in the hydration process and its conversion to monosulphoaluminate. A decrease in the level of calcium hydroxide, typical of pozzolanic activity, is not in evidence.

Keywords: *Class C high-lime fly ash; fly ash concrete; heat of hydration; X-ray diffraction; scanning electron microscopy; ettringite; monosulphoaluminate; pozzolanic reaction; crystalline structure of reaction products.*

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102. Schlorholtz, S., and Demirel, T. "Autoclave expansion of portland cement–fly ash pastes"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal I; Materials Research Society, Boston, 1984, pp. 85–93.

This paper examines the influence of the mineral composition of fly ashes on the volume stability of portland cement–fly ash pastes subjected to autoclaving. The autoclave expansion tests are performed according to ASTM C 151-81. The test results indicate that free calcium oxide dominates the autoclave expansion of portland cement–fly ash pastes. This observation is supported by a thermodynamical treatment of the hydration of CaO and MgO. Tricalcium aluminate and MgO also influence the autoclave expansion of portland cement–fly ash pastes, but to a much smaller magnitude than free lime. A multivariable model is generated in which lime, magnesium oxide, and tricalcium aluminate are the significant variables. The autoclave expansion of portland cement–fly ash pastes appears to be quite sensitive to the amount of free lime present in a given mixture.

Keywords: *autoclave expansion; fly ash–cement pastes; free calcium oxide; free magnesium oxide; tricalcium aluminate; ettringite; partial molar volume; slow hydration; soundness; quantitative X-ray diffraction; Bogue's equations.*

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103. White, E.L., Lenkei, M., Roy, D.M., and Tamas, F.D. "Effects of fly ash and superplasticizers on the rheology of cement slurries"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal I; Materials Research Society, Boston, 1984, pp. 95–106.

In this investigation, the rheological properties of oil well (Class H) cement slurries are modified with a high-calcium fly ash, a low-calcium fly ash, and three commercially available superplasticizers (two different sulphonated naphthalene formaldehyde condensates and a sulphonated melamine formaldehyde condensate) to compare the effect of each fly ash and to determine the effectiveness of each of the superplasticizing agents. The fly ashes produce remarkably different effects on the rheological properties of the cement slurries investigated. With the proportions of liquid to solid kept constant, the partial replacement of the cement by the fine particulate high-calcium fly ash generated lower viscosities/total shear stress values, while the substitution of the coarser low-calcium fly ash had the opposite effect; unless high amounts of dispersing superplasticizers were also added. The quantity of superplasticizer required to develop equivalent viscosity in mixtures of a coarse Class H oil well cement mixed with a high- and low-calcium fly ash correlated with the particle size distribution. The rheological properties of the high- versus low-calcium fly ashes mixtures are controlled by the differences in fly ash particle size and the presence of irregular large particles, rather than by the differences in chemistry between the two.

Keywords: *oil well cement (Class H); rheology; high-calcium fly ash; low-calcium fly ash; superplasticizers; sulphonated naphthalene formaldehyde condensate; sulphonated melamine formaldehyde condensate; cementitious slurry; scanning electron microscopy; particle size distribution.*

104. Chanda, S., and Bailey, J.E. "Flexural strength and fracture properties of a fly ash–blended cement"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal I; Materials Research Society, Boston, 1984, pp. 107–118.

This paper presents the results of a comparative study of flexural strength, fracture toughness, and Young's Modulus of a fly ash–blended portland cement paste (FACP) and the control portland cement paste (HCP). At comparatively early times these properties develop more slowly in FACP. However, at comparatively late ages, e.g., ten months, FACP showed improvements over HCP for all of these properties. For both FACP and HCP, the equalization points for these properties occurred any time between a few days and few months depending on the particular property being studied. The results are analysed in terms of the observed fracture mechanism for HCP by taking into account the changes brought about in the microstructure of FACP due to the incorporation of fly ash.

Keywords: *portland cement paste; fly ash–blended portland cement paste; flexural strength; fracture toughness; Young's Modulus; stress intensity factor; proportionality limit; maximum load; scanning electron microscopy; fracture surface.*

1985

Seventh International Ash Utilization Symposium and Exposition Orlando, Florida, USA, March 1985

105. Carpenter, J.W., Jr. and Hall, D.J. "The use of fly ash in articulated concrete mattress for bank stabilization on the Mississippi River"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 27–29.

This paper describes the use of fly ash as partial cement replacement in the construction of an articulated concrete mattress for bank stabilization on the Mississippi River. The essential properties of fly ash concrete such as adequate flexural strength and bonding characteristics permitted transporting, fabricating, and sinking the mattress without excessive breakage. Although economy was the primary reason for using fly ash in the concrete mix, other benefits resulted are as follows: only a minor amount of internal and external vibration of the concrete was required during casting, a smoother, more uniform surface finish on the sides and top of the mattress was obtained, clean-up of forms and mattress stacks was easier with the use of fly ash in the concrete mix. Reports show that since fly ash has been used in the concrete mattress, contractor production records have been set for the casting.

Keywords: *fly ash; articulated concrete mattress; partial cement replacement; flexural strength; bonding characteristics; production efficiency.*

106. Del Val, J., and Martin, R.G. "Pressure grouting of concrete highways and airports utilizing fly ash–cement grouts"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 30–43.

This paper presents an overview of current practice in concrete pavement jacking and grout subsealing of concrete pavements. The discussion covers: 1) material and the physical properties needed for same; 2) equipment requirements; and 3) methods and the current state of the art. The advantages of the use of fly ash–cement grout in pavement jacking and subsealing is detailed in the appendix. The particle size and shape, gradation, and pozzolanic activity are some of the properties of fly ash responsible for improved pavement jacking characteristics. A typical fly ash/cement grout mix for pavement jacking incorporates one part (by volume) portland cement Type I or Type II, three parts (by volume) fly ash, and water to achieve the required fluidity. The fineness of the fly ash and its predominantly spherical shape enables the fly ash–cement grout to be more easily pumped than those containing only cement or cement and sand or other mineral fillers. In addition, the pozzolanic reaction of the fly ash produces a more effective bond than that developed between sand and cement in weak cement grouts.

Keywords: *pressure grouting; pavement jacking; subsealing; fly ash–cement grout; hole drilling; particle size and shape; gradation; pozzolanic activity; mix design.*

107. Mings, M.L. "Pipe bedding with Class 'C' fly ash grout"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 44–49.

Class C fly ash, designated such by ASTM, possesses self-cementing properties in addition to being pozzolanic. For certain applications, the self-cementing properties provide enough strength gain to utilize the Class C fly ash without the addition of cement or lime. This paper describes one such application where Class C fly ash has been utilized in a grout mix for pipe bedding in a major aquaduct project in Oklahoma. The fly ash grout used in this project consisted of a Class C fly ash, sand, water, and a fly ash retarder to control the flash setting of the fly ash. The grout mix was designed to be flowable, and to have a minimum 14-day compressive strength of 100 psi. The fly ash grout appeared to exhibit the least segregation, bleeding, and shrinkage when compared to a portland cement grout. Further, the use of fly ash and retarder in lieu of portland cement resulted in substantial material cost savings for bedding mixes.

Keywords: *Class C fly ash; self-cementing properties; pozzolanic activity; fly ash grout; fly ash retarder; flash setting; design strength; pipe bedding; segregation; bleeding; shrinkage.*

108. Majko, R.M. "Use of fly ash–cement grout to rehab a century-old railroad tunnel"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 50–56.

This paper describes the rehabilitation of the century-old Bergen Tunnel in New Jersey, with a grout comprising four parts of Class F fly ash and one part portland cement (by volume). The grout was pumped through a series of pre-drilled holes through the inner tunnel wall, and thus filled the voids behind the tunnel to prevent water seepage that was causing stalactite formation and deterioration of the in-place electrical system. The fly ash-cement grout provided better pumpability, better penetration and void filling than the alternate cement-sand grout. The properties of the grout containing fly ash were made predictable through testing and quality assurance programs. Grouts are generally high-volume, high-priced projects, and therefore they have a good market for fly ash.

Keywords: *fly ash–cement grout; water seepage control; cohesiveness; flowability; grout penetration; strength development.*

109. Barenberg, E.J. "Cement fly ash mixes for pavements"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 57–66.

Since the early 1960s portland cement has been used as an accelerator for some lime–fly ash–aggregate mixes. It is now recognized that in many instances there would be economic as well as technical advantages in eliminating the lime and making mixes of cement and fly ash with or without aggregates. This paper presents data on some engineering properties of cement–fly ash mixes for use in pavements. Comparisons are made between the properties of lime–fly ash and cement–fly ash mixes. It is known that with lime–fly ash mixes there is an optimum lime content which produces a maximum strength, and any additional lime over this optimum may cause a reduction in strength. With cement–fly ash mixes, however, additional cement will result in high strength mixes. Both roller-compacted and plastic cement–fly ash mixes are examined. Possible savings in the amount of cement needed to produce mixes with a specified strength are provided. It is concluded that cement–fly ash mixes have the potential to provide high-quality paving materials but each mix must be verified by laboratory testing using the specific components proposed for use in construction.

Keywords: *lime–fly ash–aggregate mixes; cement–fly ash–aggregate mixes; pavement mixes; compressive strength; freeze–thaw durability; curing temperature; plastic cement–fly ash–aggregate mixes.*

110. Berry, D.H. "Illinois highways in the year one, A.F."; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 143–146.

This paper outlines the work done by the Illinois Department of Transportation on the use of fly ash in plastic portland cement stabilized sub-base (CAM II) and portland cement concrete (PCC) pavement. Prior to 1984, the sub-base options were cement aggregate mixture, pozzolanic aggregate mixture, and bituminous aggregate mixture. In 1984, CAM II was utilized, and one of the advantages of CAM II is that its plasticity allows the contractor to utilize the paving train to slipform the sub-base and eliminate the need for compaction equipment. Cement contents of 200 to 300 pounds per cubic yard are used in CAM II mixes, with the final cement content dependent upon the outcome of rapid freeze–thaw testing. For PCC pavement mixes, the minimum specified cement content is 535 pounds per cubic yard. Laboratory test data indicate that approximate equal performance between straight cement and fly ash cement could be obtained by 15 per cent by weight of cement replacement by fly ash at a ratio of 1.5:1. During 1984, contiguous sections of standard and fly ash pavements were constructed including their respective CAM II counterparts as the sub-base option. In addition, various other sections of fly ash compensated sub-base, pavement, pavement patching, and barrier median were placed. To the present, all users are satisfied with the performance of these mixes and look forward to additional applications in the future.

Keywords: *plastic portland cement stabilized sub-base; portland cement concrete pavement; minimum cement content; freeze–thaw durability; fly ash replacement; fly ash pavement performance.*

111. Collins, W. "Pozzo-crete"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 329–341.

ASTM-defined Class C fly ash has cementitious properties in addition to its pozzolanic properties. Pozzo-crete is the name given to concrete made with Class C fly ash as the primary cementing material together with small amounts of portland cement. This paper presents the work carried out on pozzo-cretes using several different fly ashes at high percentages of cement replacement. Trial batches of pozzo-crete with varying amounts of fly ash and cement were made to determine the properties such as strength, freeze–thaw durability, and sulphate resistance. The excellent results obtained prompted the use of pozzo-crete in pavement and parking lot constructions. It is concluded that although pozzo-crete cannot replace conventional concrete in all applications, there are instances where the use of pozzo-crete does have its place, especially from a cost-benefit relationship. It is suggested that pozzo-crete is suited for the following areas: parking lots, driveways, median interiors, exterior slabs, drainage ditches, and footings.

Keywords: *Class C fly ash; pozzo-crete; compressive strength; freeze–thaw durability; sulphate resistance; shrinkage; relative dynamic modulus; modulus of elasticity; abrasion.*

112. Cabrera, J.G., and Lee, R.E. "A new method for the measurement of workability of high pulverized fuel ash concrete"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 347–360.

The measurement of the workability of dry no-slump concrete manufactured with high content of pulverized fuel ash (PFA) is a practical problem for contractors attempting to produce uniform rollable mixes for the construction of dams and pavements. The Cannon method, generally used for the assessment of the water content of a high PFA–concrete mix, is qualitative in nature and thus susceptible to operator variability. This paper presents a simple quantitative method which does not depend on a qualitative assessment, but on a simple measurement. A detailed description of the apparatus and the procedure for its use is included. The paper also presents data comparing results obtained with the Cannon test and with this new test called the "Cabrera Vibrating Slump Test." Mixes designed with the new test give strengths which are higher than that of the mixes designed using the Cannon test.

Keywords: *pulverized fuel ash (PFA); high PFA concrete; workability; V-B test; slump cone; optimum water content; water-to-cementitious material ratio.*

113. Clemmons, H.D. "The use of lime-fly ash-aggregate as a stabilized road-base material"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 575–589.

This paper describes the laboratory and construction procedures together with field testing of a roadway for limestone aggregate base, stabilized with hydrated lime and a Class F fly ash. A flexible pavement of 6.25 inches in depth was placed on the lime–fly ash–aggregate (LFA) base. The mix design for the LFA material consisted of 3.5 per cent lime, 11.0 per cent fly ash, and 85.5 per cent "crusher run" limestone aggregate with approximately 8.3 per cent water in order to achieve optimum moisture. Laboratory specimens cured at 100°F had 28-day compressive strengths averaging 1,623 psi and 1,781 psi. It was determined that the mixing of lime, fly ash, and aggregate materials through an asphalt mixing plant produced a good, uniform mixture for this roadway project. Field densities ranged from 135.5 pcf to 143.6 pcf, exceeding the Proctor density. Compressive strengths of cores taken from the roadway at 6 months and 18 months were 2,093 psi and 3,382 psi, respectively. Deflections decreased by approximately 25 per cent during this period.

Keywords: *lime–fly ash–aggregate base; mix design; construction procedure; compressive strength; in-place density; deflection; flexible pavement.*

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114. Oberst, D.C. "Cement-stabilized fly ash road base"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 590–596.

This paper describes the design and construction of an experimental pavement project using fly ash–cement mixture as the base course. The objective was to construct a flexible base which would be cheaper than the bituminous base, but stronger and less susceptible to frost heave than gravel. In this project, a 10-inch thick base was constructed, chiefly of fly ash, stabilized with 10 per cent cement by weight. Several cylinder specimens were made during the construction of the base. However, the 7-day and 28-day compressive strengths of cylinders and core specimens were found to be less than the laboratory test results. Also, the material developed negligible compressive strength over the first year. The project may be said to have produced a serviceable roadway structure even though the hoped-for compressive strength was not achieved. Although this project proved to be less than successful in terms of its proposed application, the project personnel are confident of attempting to use a natural aggregate and fly ash blend as aggregate in a roller-compacted concrete application.

Keywords: *road base; cement-stabilized fly ash base; compaction; compressive strength; freeze–thaw deterioration; drainage; roller-compacted concrete.*

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115. Raba, C.F., Jr., Fetzer, D.T., Hilton, R.G., and Dougherty, E.L. "Fly ash stabilization of selected Florida subgrade and base materials"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 597–612.

Fly ash and aggregates, used alone or with cement and lime, can be used to produce high-quality base courses and improved sub-base and subgrades in flexible pavement systems. This study is directed at the evaluation of selected Florida subgrade and base materials and their engineering properties after being stabilized with fly ash, cement–fly ash, or lime–fly ash mixtures. Tests are carried out to evaluate the effectiveness of fly ash, cement–fly ash, and lime–fly ash mixtures on engineering properties including compaction, unconfined compressive strength, tensile strength, modulus of elasticity, wet–dry durability, limerock bearing ratio, and triaxial compressive strength, and the results are analysed. It is intended that these improved materials be used in unsurfaced and surfaced roads, structural fills, and embankments.

Keywords: *fly ash; cement–fly ash mixtures; lime–fly ash mixtures; flexible pavements; sub-base; subgrade; stabilizers; cementitious properties.*

116. Dolen, T.P. "The use of fly ash concrete for Upper Stillwater Dam roller-compacted concrete"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 613–639.

This paper discusses the design, construction concepts, and concrete materials investigations of roller-compacted concrete (RCC) used in Upper Stillwater Dam which is being constructed in Utah. The unique design of the dam and severe climatic conditions at the site required the use of high-strength concrete with a low heat-generating capacity. This was accomplished with 75 per cent replacement of cement with fly ash in the concrete mix design. Properties of RCC were determined from laboratory studies of mortar and concrete and from testing cores extracted from a field test placement. Extensive mix design studies were conducted including tests to determine compressive and tensile strengths and elastic properties, creep, tensile and shear strength of joints, adiabatic temperature rise, diffusivity, thermal expansion, density, permeability, drying shrinkage, and freeze–thaw resistance. Analysis of the results of the above tests and the guidelines arrived at, for the design and construction of RCC, are presented.

Keywords: *gravity dam; roller-compacted concrete (RCC); fly ash concrete; mix design; construction concepts; low-slump concrete; physical properties of concrete; slipforming; RCC quality control; accelerated strength test methods.*

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117. Smith, R.L., Fetzer, D.T., and Rugen, M.A. "Renewed attention to the use of fly ash to reduce the alkali–aggregate reaction"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 655–666.

This paper reviews some case histories and studies done in the area of alkali–aggregate reaction in concrete, and examines the use of fly ash in concrete to reduce the above reaction. The alkali–aggregate reaction is receiving renewed attention because the alkali content of cement is increasing and because aggregates previously considered non-reactive are showing signs of alkali–aggregate reaction after several years. The use of pozzolans such as fly ash to mitigate this reaction may not be effective and in fact may increase the expansion if the fly ash is characterized by a high sodium content, particularly in combination with a low silica content. The constitution and reactivity of aggregates, fly ash, and cement produced in Texas are dealt in detail. It is concluded that additional research is required to better understand the relevant parameters of the alkali–aggregate reactions in today's concrete and to develop appropriate testing procedures.

Keywords: *alkali–aggregate reaction; reactive aggregates; high-alkaline pore solution; mix proportions of concrete; effect of fly ash; concrete environment; evaluation techniques.*

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118. Joshi, R.C., Oswell, J.M., and Natt, G.S. "Laboratory investigations on concrete and geocrete with high fly ash contents"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 683–691.

In this paper, the results of studies done on the basic engineering properties of high fly ash (75% replacement of cement), non-air-entrained concrete incorporating sub-bituminous Alberta fly ashes are presented. The overall objective is to evaluate the suitability of the mixtures of cement, fly ash, and aggregate as construction materials. Compressive and flexural strengths of equivalent control mixes without fly ash are also investigated for comparison purposes. In addition, some of the selected concrete mixes, prepared through a geotechnical method (compacted at optimum moisture content and maximum dry density), called geocrete are tested for strength properties. The concrete mixes investigated are of medium to low workability, suitable for placement by slipforming and roller-compaction respectively. The test results indicate that the mixes investigated would allow the use of high fly ash concrete as a construction material for the core of a gravity dam and pavement sub-base or base courses.

Keywords: *high fly ash concrete; geocrete; sub-bituminous fly ash; compressive strength; flexural strength; indirect tensile strength; nondestructive tests; gravity dam core; pavement sub-base.*

119. Yasuda, M., and Sawada, T. "Study of FGC concrete and its use for artificial fishing reefs"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 763–775.

This paper reports on FGC concrete, a newly developed concrete incorporating fly ash, gypsum, and cement without any sand or gravel, and presents test results regarding its mix proportions, curing methods, and mechanical properties, and examples of its application to artificial fishing reefs. The gypsum used is a by-product of flue gas desulphurization and part of the fly ash could be replaced with bottom ash. By mixing the above components with a suitable amount of water, a lightweight, hardened material having strength equal to, or higher than, that of ordinary concrete is produced. Furthermore, early strength development is found to be extremely high when using sea water for mixing. FGC concrete is found to be quite stable after 3 years of curing in either fresh or sea water. FGC-made hollow cubes and hollow pyramids have been placed under sea water for testing as artificial reefs. After years of placing, the test reefs are found to be non-leaching, well stabilized, and colonized by a large number of fish.

Keywords: *FGC concrete; fly ash; gypsum; flue gas desulphurization; lightweight concrete; optimum mix proportions; mixing water; influence of sea water; curing methods; volume change; artificial fishing reef; leaching.*

120. Day, R.L., Joshi, R.C., Langan, B.W., and Ward, M.A. "Measurement of the permeability of concretes containing fly ash"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 811–821.

A number of studies done over the last several years show that the incorporation of fly ash in concrete can reduce permeability and, hence, improve the durability of concrete. This paper outlines methods which are being employed to measure the permeability of plain and fly ash concretes to water and oxygen. The choice of apparatus and the method are described. Typical results obtained from both plain and fly ash concretes are presented which demonstrate the problems encountered and how they were corrected. These problems pertain to: (i) type of permeating fluid, (ii) specimen size, (iii) length of test period to obtain steady-state conditions, (iv) seal leakage, (v) initial state of concrete at the time of test, (vi) methods of drying for oxygen permeability, and (vii) sensitivity and accuracy of measurements. The test results accentuate problems associated with measuring water permeability of concrete, whereas, oxygen permeability tests give more reliable and quicker results. However, it is suggested that the drying method may be critical to the attainment of reliable oxygen permeability results and results related to the pore structure and permeability of a saturated concrete.

Keywords: *fly ash concrete; permeability; durability; permeability test apparatus; water permeability tests; oxygen permeability tests; permeability coefficient; steady-state conditions; drying procedures.*

121. Karuks, E., and Hayes, T. "Properties of polymer and fly ash modified cementitious materials"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 822–833.

This paper reports on some of the results obtained from pilot tests forming part of a comprehensive investigation being conducted on cementitious pastes and mortars containing an acrylic polymer dispersion and fly ash. The tests carried out on pastes and mortars incorporating various percentages of polymer and fly ash relate to density, compressive strength, permeability, shrinkage, and thermal expansion. The test results indicate that correct curing procedures have a greater impact on the development of properties of polymer and fly ash modified cementitious materials than in the case of non-polymer-modified materials. No clear trend seems to exist between the water and vapor permeability coefficients and fly ash loadings, and the results show that permeability reduction could be obtained by polymer modification of the materials. The beneficial aspect of the polymer modification is demonstrated for some properties. A subsequent report containing all the results of the properties defined in the experimental program is to be presented.

Keywords: *polymer-modified cementitious composites; waterproof concrete; corrosion protection; fly ash; sulphate resistance; wet density; water absorption; mechanical properties; water and vapor permeability; thermal properties.*

122. Styron, R.W. "Fly ash lightweight aggregate: a new process"; Seventh International Ash Utilization Symposium and Exposition, Orlando, Florida, 1985, pp. 834–844.

This paper reports on a new and economical approach to the manufacture of fly ash lightweight aggregate by utilizing newly-developed accelerators and surfactant foams. This manufacturing process facilitates the production of a lightweight aggregate using fly ash, accelerator, foam, fillers, and/or portland cement. The aggregate manufacturing process and the capital costs of non-fired and fired aggregate plants are presented. Since the process is not energy intensive, a low operating cost is obtained. The use of Class C and Class F fly ashes, lightweight and conventional aggregates, accelerator, foam, and/or portland cement has been developed to manufacture lightweight products with thermal and acoustical insulating values.

Keywords: *fly ash lightweight aggregate; sintering process; accelerators; surfactant foams; portland cement; cost reduction.*

1985
ACI-RILEM Symposium 85: Technology of Concrete When Pozzolans, Slags and Chemical Admixtures are Used
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123. Diamond, S. "Influence of chemical admixtures on mix water–pore solution compositions and on early hydration"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 1–18.

This paper discusses the influences of various admixtures on the chemical composition of mix water solutions and pore water solutions of cement paste, for ages up to one day. The hydrating portland cement is considered as a solid–liquid reaction system where the basic portland cement clinker is viewed as the solid reactant and these solutions, rather than water itself, constitute the liquid reactant. The soluble alkali sulphate and alkali calcium sulphate coatings and the gypsum ordinarily present in commercial portland cement are viewed as "admixtures." The effects of adding these admixtures on solution chemistry and on heat evolution is investigated. Similar studies are reported on the influence of calcium chloride, of certain fly ashes, and of silica fume.

Keywords: *admixtures; cement hydration; pore solution; mix water solution; chemical analysis; ionic strength; potassium ions; sodium ions; calcium ions; hydroxide ions; sulphate ions; fly ash; silica fume.*

124. Jons, E.S. "SDA-ash as the only residue from flue gas cleaning"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 19–34.

The paper presents information on a new type of fly ash, spray dryer absorber ash (SDA-ash), indicating that in many applications this material shows improved properties as a mineral admixture for concrete when compared with Class C and Class F fly ashes. This ash is a by-product of flue gas cleaning by means of spray-drying absorption technology used in coal-burning power stations. The paper treats the following subjects: (i) location and amounts of SDA-ash, (ii) physical and chemical properties of the ash, (iii) mortar test comparisons of various ash types, (iv) volume stability of SDA-ash cements, (v) sulphite oxidation rates in concrete, and (vi) rational limits for chloride content in cement. The test results indicate that the SDA-ash cements tested result in volume stable, non corrosive mortars with some favorable and other acceptable technical properties, although the blended cements exceed the current limits with regard to sulphur and chloride contents.

Keywords: *spray dryer absorber ash (SDA-ash); flue gas desulphurization; calcium sulphite; fly ash; oxidation; portland pozzolan cements; volume stability; chloride; corrosion.*

125. Ramachandran, V.S. "Evaluation of concrete admixtures using differential thermal technique"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 35–52.

Thermoanalytical methods, especially the differential thermal technique, are used increasingly to evaluate concrete admixtures, to study the kinetics of hydration, relative effects of different admixtures, effects of various factors on the influence of admixtures, identification, estimation and composition of products, mechanisms, crystallinity, etc. This paper describes several applications of differential thermal analysis in the investigation of the role of admixtures such as accelerators, retarders, water reducers, superplasticizers, and mineral admixtures on the hydration of cement and cement minerals. Examples of the use of the differential thermal technique are illustrated.

Keywords: *differential thermal analysis (DTA); accelerators; admixtures; retarders; hydration; superplasticizers; fly ash; silica fume.*

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126. Atzeni, C., Massidda, L., and Sanna, U. "Rheological characteristics of blended cements"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 73–87.

This paper studies the rheological behaviour of blended cement pastes by varying the percentage of different admixtures such as blast-furnace slag, natural pozzolan, and fly ash. When examined with a rotating viscosimeter, the rheological behaviour appears to obey a parabolic law of shear rate dependence on shear stress. The yield value r_o, viscosity η, and hysteresis area A_{hys} are calculated using this model. These parameters depend on the percentage of admixture according to the expression:

$$R_x = R_o(1-X) + R_1X + K.X.(X-1)$$

where R_o, R_1, and R_x are the rheological parameters of pure portland cement, pure admixture, and the mixture respectively, X is the weight fraction of the admixture, and K is a constant. The plasticizing effect on portland cement of systems containing slag and the stiffening effect of those containing fly ash and pozzolan are explained by the differences in specific weight, fineness, and zeta potential between these materials and portland cement.

Keywords: *blast-furnace slag; natural pozzolan; fly ash; blended cement pastes; hysteresis cycle; viscosity; yield value; fineness; specific weight; zeta potential.*

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127. Day, R.L., Joshi, R.C., Langan, B.W., and Ward, M.A. "Evaluation of a foam test to assess air-entraining agent requirements in concretes containing fly ash"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 89–102.

Generally, for a given target air content the air-entraining agent (AEA) requirement in concretes varies widely. The foam test was developed to provide a rapid assessment of the AEA demand for a given fly ash–cement combination. This paper presents a laboratory study undertaken to determine the efficiency of the foam test. The tests are conducted with the following parameters varied: type of fly ash and cement, replacement level, type of admixture, length and degree of agitation of the foaming solution, effect of temperature, and effect of sample size. The results show that this test method is effective in estimating the relative AEA demand for cement–fly ash–water combinations. The foam test is also found to be relatively insensitive to factors such as speed and duration of agitation, temperature, and sample size. Good correlation is found between the foam index and the AEA requirement to produce 6.5 per cent air in laboratory concrete mixes.

Keywords: *foam test; foam index; air-entraining admixtures; fly ash; air content.*

128. Tuutti, K., and Fagerlund, G. "Fly ash – its properties and fields of application in the cement industry"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 103–119.

This paper presents a number of investigations and results which supplement previous studies of fly ash. Fly ash from coal-firing is a relatively new material to be used in the cement and concrete industry in Sweden. The investigations are confined to Class F fly ash with a low CaO content. The following aspects of fly ash are studied in these investigations: fineness, glass content, and residual carbon content of fly ash, addition of fly ash (i) to the cement when grinding cement clinker, (ii) as a partial replacement of cement in concrete, and durability aspects such as frost resistance and corrosion of reinforcement when using fly ash in concrete.

Keywords: *fly ash; particle size distribution; pozzolanic activity; residual carbon content; modified portland cement; frost resistance; corrosion of reinforcement.*

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129. Butler, W.B., and Ashby, J.B. "The influence of curing environment upon the properties of concrete made using a variety of portland cement supplements"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 197–217.

This paper presents the results of a test program which examined the effects of inadequate curing on the properties of various concrete mixtures containing up to two supplementary binders (fly ash and ground granulated blast-furnace slag) and a water-reducing admixture. Three different curing conditions consisting of standard wet-curing at 23°C, laboratory air, and laboratory air after coating with curing compound were adopted. Compressive and flexural strength development, internal moisture movement, depth of carbonation, and abrasion resistance were examined. The results indicate that portland cement concrete is as vulnerable to lack of curing as some combinations of cementitious materials. Admixture concrete shows clear superiority over plain portland cement concrete. Concrete containing fly ash and admixture achieves strength similar to plain concrete. For the portland blast-furnace slag cement mixtures, the need for water-curing seems to be more critical than normal.

Keywords: *admixture concretes; cement supplements; fly ash; portland blast-furnace slag cement; curing compound; compressive strength; flexural strength; abrasion resistance; carbonation; adsorption.*

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130. Silva, M.R., and Kuperman, S.C. "The use of set-accelerating admixtures and fly ash in shotcrete"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 219–234.

The behaviour of set-accelerating admixtures normally used in shotcrete in the presence of cement and fly ash is described in this paper. Tests are conducted to determine time of setting of cement pastes and compressive strength of mortars obtained by combining two brands of cement, one type of fly ash, and four brands of set-accelerating admixtures. The results indicate that the introduction of higher dosages of admixture in the mix can cause substantial reduction in strength when compared with mixes where the percentages are lower. Fly ash at a replacement level of 15 per cent by weight does not change the compressive strength pattern, and in most cases improves the time of initial set. At a fly ash replacement level of 30 per cent, the compressive strength at 21 days is reduced, but the time of initial set is not changed. These aspects are being studied further. It is emphasized that compatibility tests be performed before the use of any brand of cement and set-accelerating admixture in the job.

Keywords: *shotcrete; set-accelerating admixtures; fly ash; time of set; compressive strength; compatibility tests.*

131. Rossello, S.A., and Albala, J.A.L. "Study on the permeability of concretes with fly ash using the cale method"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 341–375.

This paper presents a new method for measuring the permeability of concrete to liquids and gases. The analysis and derivation of equations for the coefficient of permeability according to this method and the methodology are detailed. The experimental results of using this method on fly ash concrete are presented and the improvement on the impermeability of concrete by the use of fly ash is confirmed. The improvement is enhanced by the use of plasticizer admixtures in fly ash concrete.

Keywords: *permeability; porosity; capillarity; durability; fly ash; plasticizer admixtures; coefficient of permeability.*

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132. Damazo, D.J. "Factors influencing the mortar making properties when using portland pozzolan cement"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 377–394.

This paper presents the characteristics of cement mortars made with six different types of fine aggregates and portland–pozzolan cement. The pozzolan used is a natural pozzolan from a volcanic deposit of pumicitic toba. The gradation, shape, surface texture, and loose voids content of the fine aggregates and the properties of fresh mortar such as workability and bleeding are detailed. The test results indicate that the workability of the portland–pozzolan cement mortar is better than that of the portland cement mortar. In addition, bleeding and segregation are reduced in the portland–pozzolan cement mortars. Fine aggregates with high loose voids content are found to produce mortars with high water consumption and low strength.

Keywords: *fine aggregate; gradation; shape and texture; bleeding; compressive strength; voids content; workability.*

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133. Vazquez, E., Rovira, J., Aurin, R., and Roca, A. "Effects of accelerated curing in mortar and concrete with fly ash addition"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 415–444.

This paper investigates the effect of accelerated curing on fly ash cement mortars and concretes by means of the study of accelerated and 20°C curing and the resulting compressive strengths at 7, 28, and 90 days. Chemical and physical properties of high-calcium and low-calcium fly ashes near Catalonia, Spain, are studied. The chemical and mineralogical composition, texture, and microstructure of fly ash pastes, fly ash–cement pastes, and fly ash–cement mortars as well as the compressive strengths of the mortars and concretes are determined. After the analysis of the effect of different variables, it has been verified that strength, texture, and microstructure of 7, 28, and 90 days specimens with accelerated curing are not the same as those with 20°C curing. Several related composition–microstructure properties are analysed, and data from X-ray diffraction, scanner electronic microscopy, and mechanical properties are detailed.

Keywords: *high-calcium fly ash; low-calcium fly ash; accelerated curing; pastes, mortars; X-ray diffraction; scanning electron microscopy.*

134. Buck, A.D. "Use of pozzolan to control expansion due to alkali–silica reaction"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 501–512.

This study shows that excessive expansion (0.1 per cent) due to the alkali-silica reaction can be effectively controlled by the use of proper amount of an effective pozzolan. Two Class C fly ashes and one natural volcanic ash were selected as pozzolans and tested according to ASTM C 441 method to determine the amount of each required to reduce expansion of a test mixture by 75 per cent as compared to a control mixture. Mortar bars for expansion tests were made using combinations of one of two high-alkali portland cements (0.78 and 1.31 per cent as Na_2O), each of the three pozzolans, and pessimum amounts of Beltane Opal or reactive glassy igneous rock. The expansion tests were conducted according to ASTM C 227 for expansion at 105 to 113 days. The results show that expansions of control mortars of more than 0.4 per cent at 105 to 113 days were reduced to 0.01 to 0.02 per cent at the same ages by the use of these pozzolans. It is concluded that the use of pozzolan is a valid alternative to the use of low-alkali cement in concrete to control excessive expansion due to alkali–silica reaction.

Keywords: *alkali–silica reaction; sub-bituminous fly ash; natural volcanic ash; opal; glassy igneous rock; low-alkali cement; expansion.*

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135. Samarin, A. "Effect of pozzolans on silica aggregate–alkali reaction"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 512–528.

Methods of controlling alkali–silica aggregate reaction, and a case study achieving control of the reaction are discussed in this paper. Three means of control are presented: (i) reduction of the alkali or silica to very low levels, (ii) increase of the alkali or silica several orders above the pessimum level, and (iii) addition of a reactive pozzolanic material. The latter method is often much more practical than the other two. To control the expansion, fly ash addition should be generally in excess of 25 per cent and blast-furnace slag addition in excess of 70 per cent, both expressed by weight of portland cement. Laboratory methods of evaluating the expansive potential of concrete are also discussed.

Keywords: *alkali–silica aggregate reaction; expansion; cracking; aggregate grading; control of dimensional stability; pozzolan; fly ash.*

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136. Yuan, R.L., Cook, J.E., and Wu, D.K. "Sulfate resistance of fly ash concrete"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 529–541.

This paper investigates the sulphate resistance of mortars with (i) different percentages of fly ash content for a given water-to-cementitious material ratio and a given strength, and (ii) different water-to-cementitious material ratio for a given consistency of the fresh mortar and a given strength. In addition, the criteria of R factor on the effectiveness of the sulphate resistance is studied. Sulphate resistance tests are carried out on mortar bars using Class C and Class F fly ashes as partial replacement for cement. The results indicate that (i) Class C fly ash mortar bars reach the test procedure failure criteria for linear expansion earlier than the control mortar bars and the Class F fly ash mortar bars, (ii) for the parameters studied in this research, Class F fly ash mortar bars show significantly improved sulphate resistance, and (iii) it is possible to use the R factor of fly ash as an indicator for determining the sulphate resistance.

Keywords: *sulphate resistance; mortar; cement replacement; Class C fly ash; Class F fly ash; expansion; R factor.*

137. Al-Rawi, R.S. "Internal sulphate attack in concrete related to gypsum content of cement with pozzolan addition"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 543–556.

Normally gypsum is added to cement to retard early hydration and prevent "quick set." In many countries aggregates are contaminated with sulphates. Therefore, the total sulphate in concrete may be high enough to cause internal sulphate attack which leads to deterioration and possibly cracking and failure of concrete structures. To avoid such failures, several standards specify an upper limit on sulphate content in aggregates or on total sulphates in concrete. However, in some countries it is difficult to find aggregates which satisfy such specifications.

This work attempts to make use of the existing sand reserves in Iraq, with relatively medium sulphate content. Tests are carried out with respect to setting time, compressive strength, sulphate expansion, and ultrasonic pulse velocity on concretes incorporating gypsum-contaminated sand and portland cement prepared by decreasing the gypsum content and adding of natural pozzolan and lime to the cement clinker. The test results show that it is possible to reduce the gypsum added to cement and, consequently, raise the upper limit of sulphate content in aggregate. This will allow the use of huge reserves of sand with no durability risk or undue loss in compressive strength. The reduced grinding efficiency of cement caused by the reduction in gypsum may be overcome by addition of small percentage of pozzolan or lime. The pozzolan addition also restores the decrease in setting time caused by gypsum reduction.

Keywords: *gypsum; cement; sulphate attack; expansion; grinding efficiency; pozzolan; lime; sand; setting time; compressive strength.*

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138. Rivera, R.V. "Effect of high temperature in concretes made with fine fly ash and S.P."; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 575–596.

This investigation determines the effect of high temperature in fresh and hardened concretes made incorporating 30 per cent by weight replacement of cement by fly ash and a sulphonated naphthalene formaldehyde condensate superplasticizer. The superplasticizer is used to achieve high slumps at low water-to-cement ratios. The concretes are mixed at temperatures of 15°C, 23°C, and 38°C. Twenty-four-hour accelerated tests for compression and splitting tension as well as 7, 14, and 28 day tests for compression flexure, and splitting tension are conducted. The test results indicate that under the conditions of same slump, mixing temperature, and strength, reductions in cement consumption ranging from 30 to 40 per cent are attained for concretes with fly ash and superplasticizer when compared to reference concrete. For concretes with superplasticizer, the admixture dosage diminishes by about 4 per cent as the mixing temperature increases, whereas with fly ash incorporation the reduction is as much as 25 per cent. The effect of mixing temperature in slump influences the cement consumption. The best results are observed when the mixing temperature is around 23°C. For lower or higher temperatures the cement consumption increases, the biggest increase occurring at 38°C.

Keywords: *high temperatures; fly ash; superplasticizer; high slump; standard curing; compressive strength; flexural strength; splitting tensile strength; accelerated test; cement consumption.*

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139. Lamond, J.F. "Heat of hydration of mass concrete when pozzolans, slags and chemical admixtures are used"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 635–645.

In the design of mass concrete structures, it is necessary to assess the thermal stresses created by the temperature changes in concrete which could result in strains exceeding the thermal strain capacity of concrete. A number of factors cause thermal stresses. One of these is the temperature difference between the peak and final stable temperatures. This differential should be kept to a practical minimum value. This paper discusses methods of reducing the heat of hydration and the subsequent peak temperature in mass concrete. The combination of portland cement with pozzolans or blast-furnace slags are shown to produce less heat than an equal amount of portland cement. Water-reducing admixtures can be used to lower the water-to-cement ratio of the concrete; however, they are found to have an insignificant effect on reducing temperature rise. Design information on the heat of hydration of pozzolans and blast-furnace slags, and the various amounts of these materials to assess the thermal behaviour of the concrete structure is necessary, so that project specifications can be prepared to specify the cementitious materials which will keep the heat generation within practical limits.

Keywords: *pozzolans; blast-furnace slag; blended cements; mass concrete; temperature rise; thermal properties; admixtures; heat of hydration.*

140. Garofalo, A., and Giovambattista, A. "Effect of fly ash and accelerating admixtures on accelerated strength evaluation of plastic and fluid concretes"; ACI-RILEM Symposium 85: Technology of Concrete when Pozzolans, Slags and Chemical Admixtures are Used, Monterrey, Mexico, 1985, pp. 647–664.

This paper analyses the influence of the incorporation of fly ash and fluidizing set retarding and fluidizing strength accelerating additives on the accelerated method to evaluate strength of concrete. The accelerated curing is carried out by curing the concrete specimens for 24 hours in the moisture room followed by 3½ hours curing in boiling water. From the experimental data, regression curves are produced between concrete strength following standard curing at 28 and 60 days and strength following accelerated curing. The results indicate that the incorporation of fly ash and chemical admixtures in concrete do not influence the regression equations between strengths at accelerated and standard curing.

Keywords: *fly ash; fluidizing set retarding admixture; fluidizing strength accelerating mixture; accelerated tests; compressive strength; regression analysis.*

1985
Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II
Materials Research Society, Boston, USA, December 1985

141. Idorn, G.M. "The research–technology interface in the fly ash – concrete regime"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II; Materials Research Society, Boston, 1985, pp. 3–10.

Opportunities for development of the use of fly ash in blends with portland cement by improvement of the relevant research are discussed in view of the current modest growth of the fly ash utilization, despite copious research activity during the past decade. Refined characterization is suggested of the decisive parameters of the chemistry, mineralogy, and granulometry of both the components of the reacting, blended system, and also of the effects induced by chemical admixtures. Effective dispersion of the finest particle fractions in the fresh paste, and monitored integral hydration are indispensable successive precursors for the creation of a blended, hardened cement paste which acts as a "microconcrete," having dense matrix consisting of fully hydrated, finest fractions of both source materials and coarser unhydrated particles representing "microaggregates." Surface chemistry and energetics are emphasized as essential scientific regimes to apply for the explanatory research having as their aim substantial increases of the replacement ratios of fly ash to cement in concrete.

Keywords: *fly ash characteristics; cement characteristics; chemical admixtures; hydration reactions; fly ash–cement blends.*

142. Butler, W.B., and Mearing, M.A. "Fly ash beneficiation and utilization in theory and in practice"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II; Materials Research Society, Boston, 1985, pp. 11–17.

Over the years there have been hundreds of papers written on beneficiation of fly ash to extract alumina, magnetite, activated carbon, cenospheres, etc., and to enhance the properties of the fly ash itself for concrete making purposes. Several of the processes have been patented. Few of them have been exploited commercially. This paper examines some of the more popular processes, the history of their success or failure, and current achievements with fly ash beneficated for use in portland cement concrete.

Keywords: *metals extraction; fly ash fertilizer; cenospheres; air classification; fly ash magnetite; lightweight aggregate; fly ash concrete.*

143. Stoltenberg-Hansson, E. "Fly ash cement. Production methods, material properties, and energy savings"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II; Materials Research Society, Boston, 1985, pp. 19–26.

A standard system for grinding of portland clinker to cement and the different principles for producing fly ash cement is described. The quality is influenced by the grinding system selected. The preferred system for intergrinding of fly ash and clinker involves introduction of fly ash into the finishing compartment of the mill. Efforts made to relate cement quality to specifications are described. Much attention is directed to the physical characteristics of the fly ash: bulk weight, specific weight, particle distribution, particle shape, degree of agglomeration and colour, surface areas, and pozzolanic activity matter; but the air-void content, which is much affected by grinding, is more important. This observation is based on testing of fly ashes and fly ash cements from production and laboratory grindings. The testing includes compressive strength, specific gravity, laser granulometry, and SEM. The results have led to the introduction of new analytical and control procedures. A review of fly ash quality factors which is of most importance for cement producers is given. The energy balance in the production of blended fly ash cement involves savings from reduced consumption of clinker, and expenditure on transport, handling of fly ash and extra grinding of clinker and fly ash; net savings may be considerable.

Keywords: *fly ash cement; grinding methods; quality control factors; particle size distribution; energy consumption.*

144. Roper, H., Baweja, D., and Kirkby, G.A. "Production and characterization of fly ash from new South Wales coals"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II; Materials Research Society, Boston, 1985, pp. 115–124.

Factors affecting fly ash characteristics are examined by consideration of the various processes and constituents involved in its production. Coal conversion, boiler-furnace operations, and collection procedures are discussed. Current classification schemes applied to fly ash, in particular to those for use as a pozzolanic mineral admixture in concrete are reviewed. The variability of the material is highlighted using physical and chemical data. Shape and size characteristics of selected fly ashes from sources within New South Wales, Australia, are illustrated by electron micrographs. The influence of these properties on resultant concrete properties is briefly considered. The formation of nodules of fly ash material on the surface of fabric filters is chosen to illustrate the importance of physical and chemical conditions in the collection chamber, whereas pH changes with time of the water phase in contact with selected fly ashes demonstrate the importance of chemical characteristics of the collected materials. Such chemical characteristics may influence the path of pozzolanic reactions significantly.

Keywords: *coal properties; electrostatic precipitation; fly ash classification; scanning electron microscope studies; performance in concrete.*

145. Maage, M. "Carbonation in concrete made of blended cements"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II; Materials Research Society, Boston, 1985, pp. 193–198.

Concrete with different strength grades was produced using four types of cements: one ordinary portland cement (OPC) and three blended cements with 10 per cent PFA, 25 per cent PFA, and 15 per cent slag, respectively. The PFA was added to the cement clinker during the end of the grinding process. The slag was pre-ground. Carbonation was tested by using the phenolphthalein method. The concretes were exposed to four different climates: (1) 50 per cent RH, 20°C, and normal CO_2 content (0.03 per cent) of air; (2) 50 per cent RH, 20°C, and 0.1 per cent CO_2; (3) outside in natural environment unsheltered from rain; and (4) outside in the natural environment sheltered from rain. Curing time before exposure was varied. The preliminary results showed that concrete with blended cements carbonated somewhat faster than concrete with OPC. The influence of curing time before exposure and exposure condition was found to be evident but independent of the blend.

Keywords: *blended cements; carbonation rate; phenolphthalein test;* CO_2 *diffusion; pore structure; humidity; curing time; carbonation depth.*

146. Meland, I. "Carbonation effects in hardened fly ash cements"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II; Materials Research Society, Boston, 1985, pp. 199–206.

Carbonation in hardened pastes of fly ash cements, stored in a CO_2 atmosphere and exposed to different relative humidities, has been investigated in order to study its effects upon different properties of cement pastes. Thermogravimetry (TG), X-ray diffractometry, SEM, and mercury intrusion porosimetry (MIP) have been used to characterize the carbonation phenomenon. The results indicate that different relative humidities in the storage chambers lead to carbonation of different solid phases in the hydrated pastes. This effect is discussed in terms of TG and X-ray analysis. Changes in pore size distribution due to carbonation have been analysed by MIP and SEM.

Keywords: *fly ash cements; accelerated carbonation; corrosion of reinforcement; thermogravimetric analysis; x-ray investigations; pore volume; pore size distribution.*

147. Roy, D.M., Malek, R.I.A., Rattanussorn, M., and Grutzeck, M.W. "Trapping of chloride ions in cement pastes containing fly ash"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II; Materials Research Society, Boston, 1985, pp. 219–226.

Chloride ions, when present at sufficient concentration in the concrete pore fluid, may be associated with corrosion of the reinforcing steel even in normally passive environments. The effectiveness of fly ash containing pastes in trapping chloride ions was studied. A paste was prepared containing 30 per cent low-calcium fly ash and 70 per cent type I cement, with mixing water (50 per cent by weight) containing 0.4 per cent Cl^- with respect to the solid. Samples were cured at 25°C and 38°C at 95 per cent R.H. At designated times extending over a six-month period, the pore fluids were expressed from the hardened pastes using a squeezing cell designed for this purpose. Special precautions were taken to avoid carbonation of the fluids; contact with the atmosphere was minimized. The expressed fluids were analysed by DC plasma emission spectrometry for cations and by automated selective ion-exchange chromatography for anions. Other studies (XRD, thermal analysis) were carried out to identify the compounds formed and determine their mechanisms of formation. Investigations indicated that the mechanism of trapping chloride ions is partly chemical and partly physical through adsorption on the surface of fly ash particles (initially physical and subsequently chemical).

Keywords: *pore fluid composition; pore fluid expression studies; DC plasma emission spectrometry;* Cl^- *binding capacity.*

148. Dunstan, E.R., Jr. "A strength model for concretes containing fly ash, blast-furnace slag, and silica fume"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II; Materials Research Society, Boston, 1985, pp. 235–241.

This paper describes a preliminary model for the strength of concretes containing industrial by-products such as fly ash, blast-furnace slag, and silica fume. A formula that describes the various strength production mechanisms of these by-products is developed. These materials produce strength by pozzolanic reaction, by latently hydraulic reactions, and by self-cementing reactions similar to portland cement. A method of separating the effect of each mechanism is proposed. A parameter for each of these strength-producing mechanisms can be determined from concrete strength data.

Keywords: *pozzolanic reaction; latent hydraulic reaction; self-cementing reaction; efficiency value; Feret's relationship; potential pozzolanic property.*

149. Mills, R.H. "Evaluation of fly ash on the basis of mass equivalence, maturity equivalence and permeance"; Symposium on Fly Ash and Coal Conversion By-products: Characterization, Utilization, and Disposal II; Materials Research Society, Boston, 1985, pp. 255–262.

Combinations of two types of commercially available fly ash (FA) and portland cement (PC) were tested for compressive strength and permeance to gas flow. The cementitious components were combined in the concrete mixture in proportions PC/FA = 100/0, 75/25, 60/40, and 45/55 for a range of water-to-cement ratios, and equal workability. Strength and maturity efficiency factors were satisfactory for 75/25 and 60/40 blends. Gas tightness was improved at all levels of fly ash substitution.

Keywords: *strength; workability; maturity; mass efficiency factors; gas permeance.*

1986

Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete Madrid, Spain, April 1986

150. Gebler, S.H., and Klieger, P. "Effect of fly ash on physical properties of concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 1–50.

This paper presents results of investigations on portland cement concretes, containing Class F and Class C fly ashes from ten different sources, conducted to evaluate mixing water requirement, time of setting, bleeding, compressive strength, drying shrinkage, abrasion resistance, and absorption. The effects of moisture availability and temperature during curing were also examined. Mixing water requirement was reduced for concretes with Class C fly ash. There was no consistent water reduction when Class F fly ashes were used. Slight to significant retardation of setting time was noted for concretes with fly ash. Setting time generally increased as concrete mixing water requirement increased. Concretes with fly ash showed less bleeding than control concretes. Concretes with Class C fly ash showed less bleeding than concretes with Class F fly ash. Concretes containing Class C fly ash developed higher early-age compressive strength than concretes with Class F fly ash. Compressive strengths of concretes with Class F fly ash were more susceptible to low curing temperatures than those for concretes with Class C fly ash. At early ages, compressive strength of concretes with fly ash, regardless of class, was essentially unaffected by moisture availability. Abrasion resistance of control concretes and concretes containing fly ash was dependent on compressive strength. Drying shrinkage and absorption of the concretes were generally unaffected by the use of fly ash.

Keywords: *abrasion resistance; absorption; admixtures; bleeding (concrete); cold-weather construction; compressive strength; concretes; curing; drying shrinkage; fly ash; hardened concretes; mineral admixtures; pozzolans; setting (hardening); water content.*

151. Tenoutasse, N., and Marion, A.M. "Characterization of Belgian fly ashes and their behavior in cement paste"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 51–76.

This investigation was carried out in order to study the characteristics and chemical properties of Belgian fly ashes available for blending, prompted by the production of fly ash blended cement in Belgium during recent years. Physical and mineralogical characterization of Belgian powder fly ashes (PFAs) were performed. In order to have a better understanding of the favourable effect of the PFA on workability of fresh mortars and concrete, the zeta potential of PFA particles was measured in different conditions. The release of sulphates and alkali oxides from PFA in water, HCl, HF, blended cement, and lime-saturated solution is discussed. The pozzolanic activity of PFA was investigated by microcalorimetry and free-lime determination of the mixture. A significant pozzolanic activity was observed after 14 days. The examination of hydrated blended cement by SEM coupled with EDAX has yielded some interesting information concerning the pozzolanic reaction between the PFA particles and the calcium hydroxide generated by cement hydration.

Keywords: *cement pastes; fly ash; free lime; heat of hydration; hydration; microstructure; pozzolans.*

152. Delvasto, S. "Pozzolanic activity and characteristics of Colombian materials"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 77–90.

The objectives of this investigation are to determine (i) the pozzolanic activity of various Colombian materials, (ii) the effect of the amount of material added on the compressive strength of portland cement mortars, and (iii) the effect of curing environments on the compressive strength of fly ash–cement mortar. The effect on the properties of portland cement binders due to the addition of volcanic tuff, calcined clay, fly ash, coarse coal bottom ash, and diatomaceous earth are compared and evaluated for pozzolanic activity. Durability studies carried out for two years on mortars with addition of fly ash, in different aggressive environments, are also reported. Volcanic tuff is found to be a highly reactive pozzolan, and fly ash yields compressive strengths higher than the control after 60 days. The calcined clay reactivity is proportional to the calcination temperature. Coarse coal bottom ash has a pozzolanic activity similar to the calcined clay. Diatomaceous earth failed to produce pozzolanic activity.

Keywords: *binders (materials); calcination; clays; coal; compressive strength; curing; diatomaceous earth; fly ash; mortars; pozzolans.*

153. Aitcin, P.C., Autefage, F., Carles-Gibergues, A., and Vaquier, A. "Comparative study of the cementitious properties of different fly ashes"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 91–114.

According to ASTM Standard C 618-84, fly ashes can be classified into two broad categories depending on their chemical composition. If $SiO_2 + Al_2O_3 + Fe_2O_3 > 70$ per cent, the fly ash is said to be Class F; if 50 per cent $< SiO_2 + Al_2O_3 + Fe_2O_3 < 70$ per cent, it is said to be Class C. The physico-chemical properties of three Class F fly ashes – one French, one Canadian, and one American – and of four Class C fly ashes – two American and two French – have been investigated. It has been found that fly ashes from one particular class can behave very differently. Two Class F fly ashes have been found to be purely pozzolanic, whereas three others, one F and two C, were more or less hydraulic at an early stage of hydration before behaving like a more or less pozzolanic material. One Class C French fly ash has been found to be hydraulic, then "auto-pozzolanic"; that is, in the presence of water, its dissolution liberates enough lime to react with its own silica and alumina. Another Class C French fly ash was found to be hydraulic but non-pozzolanic, its reactivity with the lime being directly associated to the formation of ettringite. In each case, the reactivity of these fly ashes has been explained by analyzing in detail the formation mechanisms of the different hydrates.

Keywords: *bituminous coal; chemical analysis; density (mass/volume); fly ash; hydration; lignite; particle size distribution; physical properties; pozzolans; specific surface; sulphates; X-ray diffraction; X-ray fluorescence.*

154. Cabrera, J.G., Hopkins, C.J., Woolley, G.R., Lee, R.E., Shaw, J., Plowman, C., and Fox, H. "Evaluation of the properties of British pulverized fuel ashes and their influence on the strength of concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 115–144.

This paper reports the findings of an on-going study dealing with the properties of 18 pulverized fuel ashes (PFA) produced in British power stations from bituminous coals. The results reported here deal specifically with the variability of chemical and mineralogical compositions of ashes, both within and between sources (power stations). Physical properties such as particle size distribution, specific surface area, and particle shape are also analyzed. The importance of the variability of these chemical, mineralogical, and physical parameters are discussed in relation to the properties of concrete where pulverized fuel ash is used to replace 30 per cent of ordinary portland cement. A new method for the measurement of the alkali-soluble glass phase of pulverized fuel ashes is presented and evaluated in terms of the long-term strength properties of the pulverized fuel ash concretes studied. Doubts arise about the current specifications for selecting pulverized fuel ash for use in concrete, because the data accumulated during this study show that a much wider range of pulverized fuel ashes can be successfully used as a cement replacement material for the manufacture of concrete.

Keywords: *aluminum oxide; chemical analysis; concretes; evaluation; fly ash; particle size distribution; pozzolans; shape factor; silica; solubility; specific surface; strength.*

Note: Two papers of similar contents have been published by the same authors in the "AshTech Proceedings" (see abstracts 75 and 85).

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155. Swamy, R.N., and Lambert, G.H. "Shrinkage and creep behavior of concrete made with PFA coarse aggregates"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 145–170.

This paper presents comprehensive data on the shrinkage and creep behaviour of concrete made with PFA coarse aggregates and sand and having 28-day strengths of 30–60 N/mm^2. Continuously moist-cured concrete showed expansion of about 16–21 per cent of the 500-day shrinkage. At one month, some 33 per cent of the 500-day shrinkage and 50 per cent of the one-year creep occurred regardless of the concrete strength and exposure condition. The shrinkage took about one year to stabilize, whereas creep mostly stabilized in about six months. When unloaded, the fly ash aggregate concrete was able to recover all of its initial elastic strain on loading, but creep recovery was limited to about 10 per cent. The hyperbolic relation can be used to predict satisfactorily both shrinkage and creep, and these values can be used to evaluate the shrinkage and creep effects on reinforced and pre-stressed members. The paper points out that the shrinkage and creep of fly ash aggregate concrete compare favourably with those of dense concrete.

Keywords: *coarse aggregates; compressive strength; concretes; creep properties; deformation; density (mass/volume); fly ash; lightweight aggregate concretes; lightweight aggregates; shrinkage.*

156. Dunstan, M.R.H. "Fly ash as the "fourth ingredient" in concrete mixtures"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 171–200.

Fly ash is usually considered to be a partial replacement of the portland cement in concrete mixtures. This paper presents a new approach to the selection of the mixture proportions of concrete in which fly ash is considered to be the "fourth ingredient," that is in addition to the portland cement, aggregate, and water. This method enables fly ash to be used more efficiently and generally in greater quantities. High fly ash content concrete (HFCC), as the material has become known, was originally developed as a roller-compacted concrete for dam construction. The uses for the material have now been extended into road construction, both as paver-laid bases and also as pavement-quality concrete in the surface. Pumped (and skipped) structural placements have also been completed including a post-tensioned glued segmental viaduct. In all cases, the concrete has performed well both in the fresh and hardened states. The in-situ strength of high fly ash content concrete has been found to be higher than the equivalent strength of conventional portland cement concretes of equal workability and 28-day compressive strength. The paper traces the development of high fly ash content concrete and shows how fly ash can contribute as much, if not more, to the strength of a concrete as the same volume of portland cement.

Keywords: *admixtures; compressive strength; concretes; fly ash; mix proportioning; water-to-cement ratio; workability.*

157. Kropp, J., Seeberger, J., and Hilsdorf, H.K. "Chemical and physical properties of cement paste and concrete containing fly ash after hydrothermal exposure"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 201–218.

When mass concrete structures are subjected to elevated temperatures, the pore water can be liberated only in a slow drying process, causing a hydro-thermal condition, with subsequent loss in strength and modulus of elasticity. The investigation is conducted in order to explain the observed loss in strength of concrete after hydrothermal exposure, and hydrated cement paste, mortar and concrete specimens of various compositions were subjected to hydrothermal conditions at temperatures up to 250°C. Experiments on different hydrated cement systems showed that under hydrothermal conditions phase transformations in neat cement paste lead to an increase in porosity and reduction in strength. In cement pastes containing fly ash or ground quartz in sufficient amounts, gel-like compounds are formed in pozzolanic reactions during hydrothermal exposure. An increased specific surface area as well as an increase in strength is observed. Concrete exposed to hydrothermal conditions is affected by these phase transformations of the matrix; a loss in strength can be prevented by addition of fly ash or ground quartz. Because of a higher shrinkage of the modified matrix which causes increased microcracking, these concretes, however, show a loss in strength when drying during temperature exposure.

Keywords: *cement pastes; chemical analysis; concretes; fly ash; hydration; hydrothermal reactions; microcracking; physical properties; porosity; strength.*

158. Rivera, R.V. "Effect of temperature on the properties of mortars and superplasticized concrete containing low-calcium fly ash"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 219–230.

This paper reports the effect of temperature on the properties of mortars and concrete containing low-calcium fly ash. The mortars were made using ASTM methods and 30 per cent of cement (by weight) was replaced by the fly ash. The mortars were made, and test specimens were cast and cured at 15°, 23°, and 38°C. Any loss in flow was compensated for by the use of a superplasticizer. High-slump concretes in which 30 per cent of cement (by weight) was replaced by fly ash were also made; test cylinders were cast and cured at 15°, 23°, and 38°C. Once again, any loss in slump was compensated for by the use of a superplasticizer. The setting times of mortars are increased at low temperatures and their values show further increases when a superplasticizer is used. In concretes incorporating fly ash and a superplasticizer, slump loss is accelerated at 15°C, with slight retardation occurring at 38°C.

Keywords: *concretes; consistency; fly ash; low temperature; mortars (material); plasticizers; portland cement; setting (hardening); temperature.*

159. Oztekin, E. "Accelerated strength test results with pozzolanic cement concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 231–248.

This study investigates the accelerated test results of pozzolanic cement concretes. The accelerated test method used is the ASTM C 684-74 Boiling Water Method. The portland–pozzolan cement used contains 30 per cent natural pozzolan. The laboratory work involved the production of concrete mixes with cement contents of 300 to 450 kg/m^3 and water-to-cement ratios varying between 0.3 and 0.63. Maximum aggregate size was chosen to vary between 15 and 40 mm and both gravel and crushed aggregates were used. The 28-day compressive strengths ranged from 14.2 to 35.5 MPa. From each concrete mix, five 150 x 300-mm cylinder specimens were cast. Accelerated cure was applied to two specimens cast in covered moulds. The other three specimens were cured under standard conditions for 28 days. The production, curing, capping, and testing of specimens were in accordance with the relevant standards. Analysis of the results reveals a power-type relationship between the accelerated and the standard strength results and the coefficient of correlation was found as 0.967. The linear relationship also gives a high coefficient of correlation (0.963). Using the linear relationship, 28-day strengths can be estimated with 2.4-MPa accuracy within 90 per cent confidence limits. The relationship is compared to, and found to be in agreement with, those proposed by other investigators. However, accelerated strengths given by the pozzolanic cement seem to be a little higher than the others.

Keywords: *accelerated tests; cement content; compressive strength; concretes; cylinders; pozzolan cements; quality control; research; statistical analysis; water-to-cement ratio.*

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160. Carette, G.G., Malhotra, V.M., Bedard, C., De Benedictis, V., and Plumat, M. "Development of heat-curing cycles for portland cement–fly ash concrete for the precast industry"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 249–272.

This paper reports the results of an investigation to develop heat-curing cycles for portland cement–fly ash concrete for use in the pre-cast industry. The fly ash was incorporated into concrete not as a replacement for cement but as a partial replacement for fine aggregate. The variables considered were temperature of curing, pre-set time, and duration of heating. The results of the investigation indicate that portland cement concrete (W/C = 0.40) in which 18 per cent of the fine aggregate has been replaced by fly ash can be heat-cured to accelerate strength development at ages ranging from 12 to 24 h, and compressive strengths of the order of 30 to 45 MPa can be achieved at these ages. Two of the most promising heat-curing cycles for the materials under investigation consist of a 12-h cycle at 90°C with a pre-set time of 2 h and a 24-h cycle at 55° to 70°C with a pre-set time of 4 h. However, it is emphasized that pre-cast concrete producers will each have to perform investigations to optimize the heat-curing cycle that best suits their materials and production needs.

Keywords: *accelerated curing; age–strength relation; compressive strength; curing; fine aggregate; fly ash; heating; plasticizers; pre-cast concrete.*

161. Tse, E.W., Lee, D.Y., and Klaiber, F.W. "Fatigue behavior of concrete containing fly ash"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 273–290.

Because of the advantages of using fly ash in concrete pavements, and the importance of fatigue behaviour in the design and analysis of pavements, the need for further research on fatigue properties of concrete pavements containing fly ash is evident. The purpose of this study is to evaluate the fatigue properties of concretes containing fly ash and compare these properties to those of concrete without fly ash. More than 350 concrete specimens at four levels of cement replacements (0, 25, 50, and 75 per cent) and two types of fly ash (high-calcium and low-calcium) were cured for 28 days and subjected to compressive fatigue loading in which the stress varied from essentially zero to a predetermined maximum stress as percentages of the compressive strength. The fatigue strength of concrete containing fly ash is found to vary with both type of fly ash and cement replacement ratio. Concretes with equivalent or higher compressive and fatigue strengths could be obtained with cement replacement of 25 per cent by weight of low-calcium fly ash or 50 per cent by weight of high-calcium fly ash.

Keywords: *air-entrainment; compressive strength; concretes; cyclic loads; fatigue (materials); fatigue tests; fly ash; stresses; water-to-cement ratio.*

162. Bach, T. "Autoclaved cement-based products containing fly ash"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 291–312.

The use of autoclaving processes in producing cement-based products is well established. The main reason for using autoclaving processes is often to increase production rate and/or to decrease sensitivity towards variations in humidity, such as reducing moisture movements. The latter effect is mainly believed to be caused by an improved crystallinity of the finished material. The use of fly ash as the siliceous component in the base mixture is also well known. However, the crystallinity is ignored by the use of a non-crystalline base material, such as fly ash. From productions of autoclaved cement-based products utilizing silica sand, it is known that additions of small amounts of gypsum to the base mixture may improve strength and reduce moisture movements. This paper deals with the production of autoclaved materials utilizing fly ash and gypsum or its derivatives. Materials produced are characterized according to their density and strength characteristics as well as to their crystallinity. The use of gypsum or its derivatives may cause significant improvements in strength as well as in crystallinity, but the optimum design is closely related to the actual production process as well as to the chemical properties of the base materials and to the physical properties of the fly ash.

Keywords: *autoclaved products; autoclaving; fly ash; gypsum; hemihydrate; plasticizers; portland cement; silica; strength.*

163. Popovics, S. "What do we know about the contribution of fly ash to the strength of concrete?"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 313–331.

Experiments are reported where the strength development of concretes containing 75 per cent by weight of portland cement and 25 per cent fly ash with various water-to-cementitious materials ratios is investigated. The strength results of these concretes are compared not only to concretes containing no mineral admixtures but also to concretes containing 75 per cent by weight of portland cement and 25 per cent quartz powder. New as well as old experimental data seem to indicate that the contribution of fly ash to the quality of concrete is not a constant value determined solely by the physical and chemical characteristics of the fly ash but rather it can vary in different concretes. For instance, the relative contribution of a fly ash to concrete strength is increasing with decreasing water-to-cementitious materials ratio. The paper closes with a discussion of research needed for the clarification of the factors that maximize the contribution of fly ash to the strength of concrete.

Keywords: *compressive strength; concretes; fly ash; mineral admixtures; portland cements; quartz; water-to-cement ratio; water-to-cementitious materials ratio.*

164. Hooton, R.D. "Properties of a high-alkali lignite fly ash in concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 333–345.

This paper examines the properties of concrete incorporating a high-alkali, high-calcium fly ash produced from western Canadian lignite coal. Because of its high alkali content, ASTM C 441 mortar bars containing Pyrex fine aggregate and 25 volume per cent fly ash were tested initially. Even with its 2.9 per cent available alkali content, the fly ash replacement reduced expansions at one year by approximately 50 per cent relative to the high-alkali portland cement alone. Based on the C 441 results and good pozzolanic properties, a program was undertaken to evaluate the performance of this lignite ash in air-entrained concrete. In this program, strength development, air-void parameters, resistance to freezing and thawing (ASTM C 666 Procedure A), permeability, and pore size parameters were evaluated. For up to 35 weight per cent replacement with fly ash and with mixtures adjusted to constant slump, significantly lower water-to-cementing materials ratios were achieved; equal strengths were attained in only 7 days along with much higher later-age strengths; freezing-and-thawing resistance was excellent; and permeabilities and porosities were reduced. In addition, while the sulphate resistance of many lignite ashes is poor, the performance of ASTM C 1012 mortar bars with 35 weight per cent replacement for a 12.8 per cent C_3A portland cement was similar to that for moderate sulphate-resisting portland cements ($C_3A \leq 8.0$ per cent).

Keywords: *alkali–aggregate reactions; alkali content; concretes; fly ash; freeze–thaw durability; lignite; strength; sulphate resistance.*

165. Manz, O.E., and McCarthy, G.J. "Effectiveness of western U.S. high-lime fly ash for use in concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 347–365.

Western U.S. lignite and sub-bituminous fly ashes have higher $CaO + MgO + SO_3$ and lower $Al_2O_3 + SiO_2$ than bituminous ashes. They also have lower loss on ignition and greater proportions of crystalline material. No more than one-third of the total lime is free lime. In this investigation, several chemically, physically, and mineralogically different lignite and sub-bituminous fly ashes were used in varying substitutions for portland cement in concrete and tested for the following: compressive strength, effect of admixtures, freeze–thaw durability, and resistance to sulphate solutions. The test results indicate that, depending on the mix proportions, a high-lime fly ash may not contribute more to compressive strength than one that has 50 per cent less lime, and is coarser. High-lime fly ashes produce excellent freeze–thaw durability. With certain high-lime fly ashes, similar strengths are obtained by either 25 or 75 per cent substitution for cement. Extremely low expansions of several high-lime fly ash concrete specimens soaking in 10 per cent Na_2SO_4 for up to 3 years have indicated that the R factor, $(CaO\text{-}5)/Fe_2O_3$, for sulphate resistance is not totally valid. Concretes using high-lime fly ashes produce higher early strengths than low-lime bituminous ashes.

Keywords: *admixtures; compressive strength; concretes; fly ash; freeze–thaw durability; lignite; lime; sulphate resistance.*

166. Papayianni, J. "Strength and bond data for Greek high-lime fly ash concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 367–386.

The main objective of this investigation is to find the optimum proportion of cement replacement by lignite fly ash (LFA) in plain and reinforced concretes in order to obtain suitable strength and durability. Concrete mixtures are made incorporating LFA at cement replacement levels of 0, 30, 40, 50, 60, 70, 80, 90, and 100 per cent, and properties such as compressive and flexural strengths, modulus of elasticity, permeability, freeze–thaw durability, sulphate resistance, corrosion of embedded steel, drying shrinkage, creep, and others are investigated. The test results indicate that ground LFA can replace cement in the mixes up to 30–40 per cent in reinforced concrete. LFA concretes can, therefore, be used in construction for strength requirements from 15 to 30 MPa. Up to 70 per cent of LFA can be used in production of plain concrete for sub-base applications in pavement structures.

Keywords: *lignite fly ash (LFA); high-lime fly ash concrete; reinforced concrete; strength properties; modulus of elasticity; durability; cement replacement.*

167. Cuijuan, S., Luoshu, G., and Haimin, W. "Concrete made with calcium-enriched fly ash"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 387–411.

Fly ash in China contains low CaO (5 per cent) and is obtained by burning bituminous coal. Thus, concrete incorporating such fly ash exhibits low early-age strength at an optimal dosage of 10–20 per cent. This paper reports the effects of calcium enrichment of fly ash on its dosage and development of strength properties of concrete. The following two methods have been adopted to increase the calcium content of fly ash: (i) introducing calcium directly during burning, and (ii) as an additive. The effect of dosage of fly ash on strength, shrinkage, frost resistance, carbonation, and corrosion of steel in concrete is investigated. The test results indicate that the first method is effective in improving the pozzolanic activity of fly ash and permits the optimal dosage to be increased by 30–40 per cent. Early-age strength is also increased. The second method is found to be applicable to steam-cured fly ash concrete at a high dosage of 50–60 per cent. In addition, X-ray diffraction analysis is used to study the process of reaction between fly ash and cement.

Keywords: *low-calcium fly ash; calcium-enriched fly ash; carbonation; compressive strength; concrete durability; X-ray diffraction; corrosion of reinforcement.*

168. Swamy, R.N., and Mahmud, H.B. "Mix proportions and strength characteristics of concrete containing 50 per cent low-calcium fly ash"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 413–432.

Data on the mix design, strength, and elasticity properties of concrete, containing 50 per cent low-calcium fly ash replacement and a superplasticizer, for 28-day strengths of 20 to 60 MPa are presented. It is shown that for concretes with low water-to-cement ratios of 0.32 to 0.42, high early-age strengths of 12 to 20 MPa in one-day and 28-day strengths of 45 to 60 MPa can be produced with slumps in excess of 150 mm. Under wet-curing, such concretes can give strength increases of 50 to 100 per cent from 28 days to one year compared to increases of 18 to 25 per cent for all OPC concretes. Even under the worst curing conditions, fly ash concretes showed a slow but steady strength gain and maintained their target strengths at one year whereas all OPC concretes under similar conditions showed strengths which were 25 to 35 per cent below the target strength. Air drying always produced greater losses in strength and elasticity in all OPC concretes than in fly ash concretes. The latter were able to develop flexural strengths of 3.5 to 6.0 MPa and tensile splitting strengths of 2.0 to 4.5 MPa at one year under these conditions. The practical and technical benefits of incorporating high fly ash contents in concrete are emphasized.

Keywords: *compressive strength; concretes; curing; flexural strength; fly ash; high-strength concrete; mix-proportioning; modulus of elasticity; plasticizers; stress–strain relationships; tensile strength.*

169. Nasser, K.W., and Al-Manaseer, A.A. "Shrinkage and creep of concrete containing 50 per cent lignite fly ash at different stress–strength ratios"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 433–448.

This paper reports on a study conducted to find the shrinkage and creep of sealed and unsealed concretes made with Type 1 cement and containing 50 per cent Saskatchewan fly ash. The tests were carried out at different stress–strength ratios and creep was measured at those ratios of: 10, 20, 30, 40, 50, and 60 per cent and for a maximum period of 112 days. All the tests were carried out at room temperature of 70°F (21.4°C). Experimental results showed that creep of concrete made with 50 per cent fly ash was a linear function of the stress–strength ratio. The shrinkage of this concrete was about 11 per cent higher than that of plain concrete, while its creep was lower by about 13 per cent for the unsealed specimens and 39 per cent for the sealed ones. In addition, the ratio of creep values of unsealed to sealed concrete was about 2.44 for plain concrete and 3.67 for concrete with 50 per cent fly ash.

Keywords: *age–strength relation; concretes; creep properties; creep tests; curing; fly ash; shrinkage.*

170. Heikkinen, A. "Use of peat ash in concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 449–461.

Peat is commmonly used as a fuel in power plants in central and northern Finland, Ireland, and the Soviet Union. Peat is extracted from the surface of marshes using lighter equipment than that needed for coal. Locally available peat is used as a power plant fuel, if coal has to be hauled over long distances. This paper reports on some preliminary work carried out on concrete incorporating peat ash as a partial replacement of cement. Compressive strength tests were conducted on concretes incorporating varying peat ash contents and different admixtures. The test results indicate that peat ash is suitable for use as a constituent of concrete. The quality and quantity of admixtures and ash used in concrete have a strong influence on the development of compressive strength. It is concluded that further tests on the durability aspects of peat ash concrete are necessary, before such concrete can be used on a larger scale.

Keywords: *peat ash; cement replacement; peat ash concrete: admixtures; compressive strength; chemical composition of peat ash.*

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171. Roper, H., Kirkby, G., and Baweja, D. "Long-term durability of blended cement concretes in structures"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 463–482.

Although abundant data are available on early-age properties of blended cement concretes, relatively little information has been published on the long-term durability of blended cement concretes in service. This paper is a summary of an investigation of over 200 structures in Australia. Some of these have service lives in excess of 20 years. Cored materials from some of the structures are described, and petrological and mineralogical examinations allow conclusions of the efficacy of hydration processes under field-curing to be made. Porosity and permeability are discussed. Carbonation and corrosion effects on long-term durability are considered by the examination of data obtained from in-situ concretes. The interactions between cement content and water-to-cement ratio on carbonation rate are discussed, and data from concretes both from in-service and laboratory mixes are considered. Cracking is the predominant defect observed on most of the examined concrete surfaces and the role of pozzolans on elastic deformations, creep, and shrinkage of concrete in structures is discussed. Data suggest that, for those structures studied, the long-term durability of blended cement concretes is at least the equal of ordinary portland cement concretes under service conditions.

Keywords: *blended cements; buildings; canals; concrete dams; concrete durability; fly ash.*

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172. Gebler, S.H., and Klieger, P. "Effect of fly ash on the durability of air-entrained concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 483–519.

In this investigation, concretes containing fly ash were evaluated to establish the effect of fly ash on freeze–thaw resistance, resistance to de-icer scaling, and chloride ion penetration. The effects of low-temperature curing and moisture availability during curing were also evaluated. These tests indicated that the freeze–thaw resistance of air-entrained concrete was reduced by the use of certain fly ashes when cured at low temperature. For other conditions, there was no significant influence of fly ash. De-icer scaling resistance tests showed that air-entrained concrete without fly ash generally performed somewhat better than concrete with fly ash, regardless of the type of curing provided. Air-entrained concretes made with some fly ashes were as resistant to chloride ion penetration as air-entrained concrete without fly ash. The class of fly ash did not significantly influence the degree of chloride ion penetration.

Keywords: *admixtures; air-entrained concretes; chlorides; cold weather construction; concrete durability; corrosion; curing; de-icers; fly ash; freeze–thaw durability; mineral admixtures; permeability; pozzolans; scaling.*

173. Nagataki, S., Ohga, H., and Kim, E.K. "Effect of curing conditions on the carbonation of concrete with fly ash and the corrosion of reinforcement in long-term tests"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 521–540.

This paper reports the long-term results of experiments carried out since 1969 to investigate the carbonation phenomena in concrete with and without fly ash. They were carried out for different mix proportions by varying cement factor, replacement ratio of fly ash, and water-to-cement ratio. The specimens were cured indoors and outdoors after water-curing for periods of 1, 7, 28, and 91 days. The test results indicate that carbonation and corrosion are considerably affected by mix proportions, initial curing period in water, and exposure conditions. Depths of carbonation of concrete cured indoors increase with age, short initial curing period in water, and high water-to-cement ratio. Corrosion of reinforcing bar embedded occurred due to the carbonation.

Keywords: *carbonation; corrosion; curing; exposure; fly ash; mix-proportioning; pozzolans; reinforced concrete; reinforcing steels.*

174. Paillere, A.M., Raverdy, M., and Grimaldi, G. "Carbonation of concrete with low-calcium fly ash and granulated blast furnace slag: influence of air-entraining agents and freezing-and-thawing cycles"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 541–562.

This investigation deals with (i) carbonation of concrete as a function of the nature of cement (i.e., portland cement and blended cements with fly ash or slag), and (ii) the combined effect of freeze–thaw cycles and carbonation as a function of the nature of cement and the air content in mortars. Air-entrained cement mortars made with various types of cements and varying air contents were subjected to carbonation and freeze–thaw cycles. The carbonation depth and compressive strength were determined on all samples. The test results indicate that the carbonation of concrete is increased (i) in the presence of a high percentage of granulated blast-furnace slag in the cement, and (ii) after subjecting concrete to freezing and thawing cycles. Uncarbonated concrete resists freezing and thawing better than concrete carbonated previously. Air-entraining agents do not modify the carbonation when the concrete containing portland cement or cements with low-calcium fly ash and granulated blast-furnace slag (<20 per cent) is subjected to freeze–thaw cycles.

Keywords: *carbonation; low-calcium fly ash; blast-furnace slag; blended cements; air-entraining agent; air content; freeze–thaw durability; compressive strength.*

175. Saeki, N., Fujita, Y., and Takada, N. "Surface layer strength of concrete as a measure of scale resistance"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 563–590.

The properties of the surface layer of concrete may be closely related to the causes of scaling and play an important role in the durability of concrete. In order to obtain the mechanical properties of the surface layer, which are affected by the type of cements, curing, and atmospheric condition etc., some tests were carried out by using model specimens with penny-shaped cracks (penny-shaped crack test) or truncated steel core (pull-out test). The ratio of the surface layer strength to splitting tensile strength was found to be approximately proportional to the thickness of the layer. The surface layer strength is influenced by the curing conditions and is related to the degree of scaling and frost damage.

Keywords: *concrete durability; cracking (fracturing); curing; freeze–thaw durability; scaling; strength; surface defects; thickness.*

176. Meland, I. "Use of fly ash in cement to reduce alkali–silica reactions"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 591–608.

This report presents results from an investigation where fly ash has been used in cement to try to reduce an observed alkali–silica reactivity in tile-covered mortar and concrete constructions such as swimming pools and larger shower cabinets. Examinations of ceramic tiles showed that soluble silica formed when the material was exposed to sodium hydroxide solution. For testing according to ASTM C 227-81 "Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)," concrete prisms were moulded using ordinary portland cement or fly ash cement with crushed ceramic tiles as aggregate. All the prisms showed changes in length; however, the changes are less in prisms made with fly ash in cement. From these observations, it appears that it is possible to reduce the damage caused by alkali–silica reactions in such structures by use of fly ash in cement. Long-term tests are being done on tile-covered concrete slabs.

Keywords: *alkali–aggregate reactions; cements; ceramic tiles; concretes; fly ash; mortars (material); silica.*

177. Andrade, C. "Effect of fly ash in concrete on the corrosion of steel reinforcement"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 609–620.

The replacement of portland cement in concrete by blended materials may affect the excellent protective properties of the concrete vis-à-vis the steel reinforcement. Although the blended materials produce the favourable effect of increasing the concrete impermeability and density, they decrease the alkalinity. This paper presents a preliminary study of the effect of two fly ashes (silico-aluminous and sulpho-calcium), added to concrete and mortar, on the steel passivation. In order to evaluate the possible corrosion of reinforcement bars, the polarization resistance and the impedence techniques of measurements were used. The specimens were kept in a chamber with 90–100 per cent relative humidity for about two months. The test results show that the protective properties of the concrete vis-à-vis the steel bars are not altered by the blended materials, whereas in the mortars some proportion of the fly ashes may induce localized corrosion.

Keywords: *corrosion of reinforcement; carbonation; fly ash; concretes; mortars; sulphates; polarization; resistance technique; steel passivation; chlorides.*

178. Backes, H.P. "Carbonic acid corrosion of mortars containing fly ash"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 621–636.

The influence of replacing cement by fly ash on the resistance of mortars against carbonic acid attack has been investigated according to the German standard DIN 1045. The tests have been carried out with cements PZ 35 F (portland cement) and HOZ 35 L (blast-furnace slag cement), two different fly ashes, three different water-to-cement ratios of the initial mortars without fly ash, and with constant flow value in all cases. The fly ash (f)-to-cement(c) proportion was varied from f/c = 0.25 to 1.00. After certain periods of storing, values have been measured as follows: mass and volume of test specimens, bulk density, resonance frequency by longitudinal activation with regard to the dynamic modulus of elasticity, compressive strength, depth of carbonation, and water absorption. The investigations on mortar prisms stored in water with a carbonic acid concentration of more than 60 mg CO_2/l for 4 years showed that replacement of cement with fly ash can slow down the rate of attack. The loss of mass as a significant value essentially depends, under the same conditions, on the porosity of the hardened cement paste. It can be considerably influenced by using selected fly ashes.

Keywords: *acid resistance; carbonation; cement; chemical attack; compressive strength; corrosion; durability; fly ash; mortars (material); non-destructive tests; porosity.*

179. Mehta, P.K. "Standard specifications for mineral admixtures – an overview"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 637–658.

There is a growing concern that the existence of prescriptive and separate standards is one of the obstacles preventing the large-scale use of by-product mineral admixtures for concrete, such as fly ash, granulated slag, and condensed silica fume. Because natural pozzolans as well as by-product pozzolanic and cementitious admixtures offer similar technical benefits when used in concrete, it is desirable to develop a single performance-oriented standard. With this objective, the principal chemical and physical requirements of a few selected standards are critically reviewed. With a special focus on fly ash, the significance of these requirements and their relevance to today's materials are examined. In the end, a rational approach is suggested and specific recommendations are made towards the goal of developing a performance standard covering all mineral admixtures.

Keywords: *blast-furnace slag; chemical analysis; fly ash; mineral admixtures; performance; physical properties; pozzolans; silica; specification; standards.*

180. Manz, O.E. "Proposed revisions to specifications and test methods for use of fly ash in portland cement concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 659–680.

Many of the current standards for fly ash for use in portland cement suffer from prescriptive requirements which are not necessarily related to the performance of the material in concrete. The development of performance specifications is being encouraged. Classification of fly ash by reference to the type of coal is being questioned. For fly ash to be used as a mineral admixture, potential strength contribution to a reference mortar seems to be the most important consideration. To overcome the inconsistency in the ASTM C 311 pozzolanic activity index with cement, many countries have revised the test by incorporating fixed fly ash-to-cement ratio by weight, fixed water-to-(cement + ash) ratio, and accelerated curing at various temperatures for up to 7 days rather than 28. In this paper, a summary is presented of the various studies to improve pozzolanic activity test methods. Recommendations are made to simplify the present fly ash standards and to make them performance-oriented rather than prescriptive.

Keywords: *concretes; fineness; fly ash; free lime; performance; pozzolans; setting (hardening); specifications.*

181. Walsh, P.F. "Fly ash and durability in the Australian concrete code"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 681–692.

In drafting the durability section of the Australian concrete code, the committee was faced with an urgent problem but lack of precise data. This paper outlines the concepts in the draft code with particular emphasis on the protection of reinforcement and the influence of fly ash on durability. Based on a qualitative understanding of the fundamental parameters, some engineering decisions and classifications are made. It is concluded that where ample curing or self-curing is available, fly ash is a desirable component of durable reinforced concrete. For building exteriors, where minimal curing is provided, the achievement of quality concrete cover is difficult. In this respect, concrete containing fly ash may be more affected than plain concrete.

Keywords: *carbonation; concrete durability; curing; fly ash; pozzolans; reinforced concrete; standards.*

182. Dhir, R.K., Hubbard, F.H., Munday, J.G.L., and Jones, M.R. "Characteristics of low-lime fly ashes significant to their use in concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 693–721.

In this investigation, the results of studies undertaken into the compositional and physical characteristics of a wide spectrum of U.K. fly ashes, and some from overseas, are examined in conjunction with data available from the literature. No direct relationship was found to exist between the compositional nature of a fly ash and its behaviour in concrete. The single most significant physical parameter characterizing ash is shown to be fineness (as measured by 45-μm sieve retention) and is used in developing two schemes classifying (a) the water-reducing and (b) the cement-saving abilities of an ash, which give a simple measure of ash suitability for use in concrete. It is demonstrated that for a correctly designed concrete, the grade of ash does not significantly affect its engineering properties, but only the cement savings that can be achieved.

Keywords: *cement content; chemical analysis; concretes; fineness; fly ash; mechanical properties; water content; workability.*

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183. Helmuth, R.A. "Water-reducing properties of fly ash in cement pastes, mortars, and concretes: causes and test methods"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 723–740.

Specifications for fly ashes should be based on a proper understanding of the test methods and factors controlling the water requirements for flow. The reduction of the water requirement for flow of concretes which results from partial replacement of portland cements by certain fly ashes is commonly attributed to the spherical shape of many of the fly ash particles. Critical re-examination of the literature does not support that conclusion. An alternative hypothesis is proposed in this paper: the water reduction is a result of adsorption of very fine fly ash particles on portions of the cement particle surfaces, with resulting dispersion of the cement particles, similar to the action of organic water-reducing admixtures. This hypothesis is consistent with published data on fly ash-cement-admixture interactions. This effect should be separated from that of the amount of fly ash coarser than 45 μm in the test methods and specifications, but is not in the present ASTM C 311 test for water requirement.

Keywords: *cement pastes; concretes; fly ash; mortars (material); portland cements; tests; water content; water-reducing admixtures.*

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184. Valenti, G.L., Cioffi, R., and Sersale, R. "Production and utilization of fly ash in Italy"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 741–762.

The objective of this investigation is to examine the characteristics of some typical fly ashes produced in Italy, and to evaluate their technical behaviour when mixed with lime or portland cement. The fly ashes produced in Italy generally show good pozzolanic behaviour. Tests made on lime and cement mortars have shown that four of the five ashes give comparable or even superior performance to that of a natural pozzolan usually employed in the production of portland pozzolan cements. The chemical characteristics were: SiO_2 42.7–50.2 per cent; $SiO_2 + Al_2O_3$ 66.5–77.2 per cent; $SiO_2 + Al_2O_3 + Fe_2O_3$ 75.8–83.5 per cent; loss on ignition 3.9–12.9 per cent; and CaO 1.8–9.3 per cent. The calcium oxide content is the parameter that greatly influences the technical behaviour. Glass content ranging from 63 to 75 per cent does not have a dominant influence on mechanical strength. The particle size distribution, rather than the fraction <45 μm determines the mechanical characteristics.

Keywords: *Blaine method; calcium oxides; cements; chemical analysis; fly ash; lime; mechanical properties; mortars (material); particle size distribution; pozzolans; strength.*

185. Ispas, T., and Ionescu, I. "Production of fly ash concretes using superplasticizers"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 763–778.

This paper presents results of investigations on the practical utilization of fly ash in concrete with and without superplasticizers. The influence of superplasticizers on the hardening process of fly ash concretes was studied at varying ages up to 730 days. The test results indicate that fly ash can be used to advantage in non-superplasticized concrete at a replacement level of up to 50 per cent by weight of portland cement, and up to 25 per cent by weight of cement with 15 per cent of admixture in superplasticized concrete. The addition of fly ash and superplasticizer to concrete shows additional advantages such as high initial and ultimate strengths, increased resistance to repeated freeze–thaw cycles, better durability, and reduction in energy required for heat-curing.

Keywords: *admixtures; fly ash; superplasticizers; heat treatment; air-entrainment; freeze–thaw durability; permeability; strength; setting and hardening; workability; carbonation.*

186. Bentur, A., Ish-Shalom, M., Ben-Bassat, M., and Grinberg, T. "Properties and application of oil shale ash"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 779–802.

In recent years, there has been a renewed interest in the utilization of oil shales as a source for energy production and this was accompanied by research and development aimed at finding ways to utilize the ash by-product as a building material. The present paper discusses the various types of oil shale ash and their possible applications, and reviews recent studies carried out in Israel to utilize the cementitious characteristics of oil shale ash. The composition and properties of the oil shale ash can vary widely, ranging from high-SiO_2 materials which are only pozzolanic in nature, to higher-CaO oil shale ash which can be hydraulic and can serve as a cementitious matrix without any need for an activator. Therefore, each type of oil shale ash must be evaluated separately. The experience and knowhow gained in the application of one kind of oil shale ash may not be relevant to others. This is considerably different than with other residues, such as fly ash, which do not exhibit this extent of variable properties.

Keywords: *ashes; blended cement; chemical analysis; concretes; oil shale; physical properties; portland cements; workability.*

187. Verhasselt, A. "Low-calcium fly ash as a mineral admixture for lean concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 803–820.

The use of fly ash as a mineral admixture for lean concrete (road base concrete) has aroused a rather limited interest until now. However, this comparative study shows that there are some advantages in using low-calcium fly ash in lean concretes. The compactibility of lean concrete is improved: the maximum level of compaction (Modified Proctor test) is achieved at about 5 per cent fly ash addition, whereas it is equal at 0 per cent and 10 per cent addition. The CBR indexes of the mixes are similar at Proctor maximum, but the higher the fly ash content, the more sensitive the index is to an increase in moisture content. At an early stage, fly ash is not very effective in strength development: it is essentially the portland cement content (2 to 5 per cent) that governs the rate of strength evolution. On the other hand, at longer periods (more than 6 months), fly ash contributes very largely to strength: a factor of 1.5 between the weakest mix and the reference lean concrete without fly ash. Accordingly, a reduction of the cement content in practice can be taken into consideration. Water stability which is obtained rapidly is not much affected by the presence of the admixture. On the other hand, resistance to repeated freezing and thawing cycles is delayed because of the slower strength gain for mixes containing more fly ash and less cement. The results on the whole show that the optimum low-calcium fly ash content in lean concrete for road base lies around 5 per cent by mass with the possibility of reducing the cement content appreciably.

Keywords: *admixtures; age–strength relation; bearing capacity; cement content; compaction; compressive strength; concretes; fly ash; freeze–thaw durability; lime; portland cement; splitting tensile strength; ultrasonic tests.*

188. Ramakrishnan, V. "Evaluation of kiln dust in concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 821–839.

Dust collected from the hot exhaust gases emanating from the rotary kiln is known as cement kiln dust and at present it is considered as a solid waste material to be disposed of without polluting the environment. The composition of this dust is similar to that of cement kiln raw feed and often contains high concentration of alkalis. It contains partly calcined material and therefore it has some hydraulic and cementitious properties. This paper presents the results of a comparative study of the properties of concretes made with cement blended with kiln dust versus the properties of corresponding concretes made with plain portland cement. The blended cement was produced by blending 5 per cent cement kiln dust with 95 per cent by weight of regular Type I portland cement. Cement properties, mortar properties, fresh concrete properties, and hardened concrete properties such as compressive strength, splitting tensile strength, flexural strength, impact strength, static modulus of elasticity, shrinkage, creep, and creep recovery were studied using ASTM test procedures.

The result of the study showed that the addition of cement kiln dust slightly retards the setting time of cement and the fresh concrete properties of blended cement concrete mixes were almost the same as those of plain cement concrete mixes. Blended cements did not adversely affect most of the hardened concrete properties.

Keywords: *blended cements; compressive strength; concretes; creep properties; dust; dust collectors; evaluation; kilns; setting (hardening); shrinkage; tensile strength; wastes.*

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189. Maage, M. "Strength and heat development in concrete: influence of fly ash and condensed silica fume"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 923–940.

In order to reduce energy, save raw materials, and improve mechanical properties, different pozzolans are now commonly used in cement and concrete production. A comprehensive research program was undertaken where cement and concrete properties, influenced by fly ash and condensed silica fume in different combinations, were investigated. This paper presents their influence on strength and heat development. The program included an ordinary portland cement and two blended cements with 10 per cent and 25 per cent fly ash respectively. The three cements were combined with 0 per cent, 5 per cent, and 10 per cent condensed silica fume. Curing temperatures used were 5°, 20°, and 35°C. Condensed silica fume is very finely graded and the content of amorphous SiO_2 is very high. The pozzolana reaction therefore starts early, at 20°C from around 7 days, at 35°C from around 2 days. At 5°C, no pozzolana reaction was observed for the first 28 days. The pozzolana reaction from fly ash was found to be slower than the reaction from condensed silica fume, probably due to the coarser grinding and the lower SiO_2 content.

The compressive strength results indicated that the pozzolana reaction was more sensitive to the temperature than the reaction involving cement hydration alone. The slow strength development of concrete when using fly ash in blended cements can be avoided by grinding the cements to a higher fineness. The effect on strength development when using condensed silica fume was approximately the same in all three types of cement investigated. The heat development was higher in pure portland cement than in blended cements. However, when adding condensed silica fume, the heat development increased. Maturity functions were found to be valid up to maturities corresponding to curing at 20°C for approximately 2 days.

Keywords: *age–strength relation; blended cements; compressive strength; concretes; curing; fly ash; heat of hydration; silica; temperature.*

190. Nagataki, S., and Ujike, I. "Air permeability of concretes mixed with fly ash and condensed silica fume"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 1049–1068.

The objective of this study was to investigate the behaviour of air flow through concrete and to make clear the effects of use of fly ash and condensed silica fume on the air permeability of concrete. The air permeability of concrete was estimated by means of the coefficient of air permeability, and the difference in the coefficient of air permeability between concretes with and without fly ash and condensed silica fume was investigated. Furthermore, the improvement of the airtightness of concretes with fly ash and condensed silica fume was discussed from the viewpoint of the internal structure of concrete such as porosity. As a result of this study, it was confirmed that the flow of air through concrete obeyed Darcy's law. It is possible to apply the coefficient of air permeability as the index of air permeability of concrete. In the case of use of fly ash, the coefficient of air permeability of concrete cured in water for the period of 28 days had almost the same value as that of concrete without fly ash when compared at the same level of compressive strength. However, the concrete with fly ash cured in water for the period of 91 days is more airtight than concrete without fly ash. In case of use of condensed silica fume, the coefficient of air permeability decreased with the increase of replacement ratio of condensed silica fume, and did not depend on the period of the curing in water. These results can be quantitatively understood by means of the internal structure of concrete.

Keywords: *air; concretes; Darcy's law; drying; fly ash; permeability; porosity; silica.*

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191. Kakizaki, M., Okamoto, K., and Takano, T. "Study of cast-in-place high strength concrete made with silica fume, alumina-type mineral, and fly ash"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 1185–1214.

In this study, three kinds of inorganic mineral admixtures (silica fume, alumina-type mineral, and fly ash) were mixed with cement and aggregates to have a low water-to-(cement + condensed admixture) ratio using high-range water-reducing agent. This study clarified both the properties of fresh concrete and adequate concrete mix proportions. This test was made by dividing eight factors and three levels among the orthogonal array of L_{27} based on test plan method. The test results indicate that flowability of fly ash concrete and alumina-type mineral concrete is increased with increase in dosage of admixture, but that of silica fume concrete is decreased. In order that concretes with various admixtures have the same flowability (a slump of 18 cm for concrete without admixture), at a certain dosage of admixture (x 1.6), the slump value is about 21 cm with silica fume concrete, about 6 cm with fly ash concrete and about 16 cm with alumina-type mineral concrete. Fly ash concrete and alumina-type mineral concrete show more segregation of aggregate. Silica fume concrete shows less with the passage of time. Unit water content for all cements and aggregates can be determined by ordinary mix proportion. Air-entraining-agent content required to get the same air content increases with increase in the amount of mineral admixture and superplasticizer.

Keywords: *admixtures; air-entraining agents; aluminum oxide; concretes; consistency tests; fly ash; high-strength concretes; mineral admixtures; mix-proportioning; plasticizers; silica; slump tests; temperature; water content; workability.*

192. Wakeley, L.D., and Buck, A.D. "Effects of different fly ashes and silica fume on selected properties of an expansive grout"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 1261–1278.

In this investigation, an expansive grout based on Class H cement, an expansive admixture consisting essentially of plaster of paris (calcium sulphate hemihydrate), and a Class C fly ash was proportioned for use underground. Specimens of this grout, and of five modified versions of it, were tested to determine the effects of using two other fly ashes, with or without silica fume, on compressive strength, volume change, phase composition, and microstructure. Properties were monitored to 960 days age. Up to 365 days age, specimens of the mixture modified with Class F fly ash had lower compressive strengths and generally more expansion than did those of the original composition. At ages of 90 days and greater, the same was true of samples prepared with a second Class C fly ash. Substitution of silica fume for 5 or 10 per cent of the cement gave higher early-age strength, but the combination of the second Class C fly ash and 10 per cent silica fume gave the lowest strengths at ages of 90 days and greater. Despite the substitutions, properties were markedly similar, compressive strength from all modifications exceeded 90 MPa at 365 days, and phase composition and micro-structures became more similar with time.

Keywords: *compressive strength; expanding agents; expansion; fly ash; grouts; microstructure; permeability; silica; X-ray diffraction.*

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193. Kohno, K., and Komatsu, H. "Use of ground bottom ash and silica fume in mortar and concrete"; Second CANMET/ACI International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, 1986, pp. 1279–1292.

This paper describes an investigation of the use of industrial by-products such as bottom ash and silica fume with high silica content, as the admixture for mortar and concrete. The bottom ash used for this investigation was ground in a ball mill. At first, basic tests using mortars were conducted. Subsequently, the concretes containing different proportions of the two by-products were tested for strength development under accelerated curing, drying shrinkage, and water permeability. The results of the mortar strength tests indicate that the proper amount of ground bottom ash is about 5 per cent if used to replace cement or 10 per cent if used in addition to cement, and that of silica fume is approximately from 5 to 10 per cent if used to replace cement and from 10 to 15 per cent if used in addition to cement. When steam curing and autoclave curing are used, the concretes containing ground bottom ash and silica fume have higher early compressive strength than concrete without these materials. The coefficients of water permeability of the concretes using ground bottom ash and silica fume are lower than those of concrete without these materials. Particularly, the watertightness of silica fume concrete improved remarkably, although the concrete has a little higher drying shrinkage in comparison with concrete without silica fume. The use of these materials in amounts of 5 to 10 per cent to replace cement is effective for the improvement of concrete properties.

Keywords: *accelerated curing; ashes; autoclaving; compressive strength; curing; drying shrinkage; flexural strength; mix-proportioning; permeability; silica; steam curing; tensile strength.*

AUTHOR INDEX[1]

Aitcin, P.C. 153
Albala, J.A.L. 84, 131
Ali, S.A.R. 70
Al-Manaseer, A.A. 169
Al-Rawi, R.S. 137
Andrade, C. 177
Ashby, J.B. 31, 56, 129
Atzeni, C. 126
Aurin, R. 133
Autefage, F. 153

Bach, T. 162
Backes, H.P. 178
Bailey, J.E. 104
Baker, M.D. 101
Bamforth, P.B. 73
Banfill, P.F.G. 39
Barenberg, E.J. 109
Barker, W.R. 21
Baweja, D. 144, 171
Bedard, C. 160
Ben-Bassat, M. 186
Bentur, A. 186
Berry, D.H. 110
Bhagrath, R.S. 68
Blackie, A.D. 46
Boas, E.A. 94
Bordonado, G. 67
Brooks, J.J. 41, 76
Brown, J. 19
Brown, J.H. 38
Browne, R.D. 74
Buck, A.D. 134, 192
Butler, J.E. 93
Butler, W.B. 129, 142
Buttler, F.G. 1, 12, 65

Cabrera, J.G. 9, 75, 85, 112, 154
Cain, C.J. 20
Carette, G.G. 160
Carles-Gibergues, A. 153
Carpenter, J.W., Jr. 105
Chanda, S. 104
Chehovits, J.G. 29
Cioffi, R. 184
Clemmons, H.D. 113
Clendenning, T.G. 53
Collins, W. 111
Cook, J.E. 44, 62, 136
Copeland, B.G.T. 49
Coyle, W.V. 19
Cripwell, J.B. 41, 76
Crow, R.D. 17
Cuijuan, S. 167

Damazo, D.J. 132
Day, R.L. 83, 120, 127
De Benedictis, V. 160
Decter, M.H. 65
Del Val, J. 106
Delvasto, S. 152
Demirel, T. 102

---

[1] Numerals indicate abstract numbers in the text.

Dhir, R.K. 16, 40, 43, 60, 78, 182
Diamond, S. 99, 123
Dodson, V.H. 13, 15
Dolen, T.P. 116
Dougherty, E.L. 115
Dunstan, E.R., Jr. 17, 148
Dunstan, M.R.H. 45, 156

Ellis, C. 36, 77

Fagerlund, G. 128
Fajun, W. 100
Fetzer, D.T. 115, 117
Follett, P.M. 96
Fox, H. 154
Fujita, Y. 175

Garofalo, A. 140
Gebler, S.H. 55, 150, 172
Gifford, P.M. 42
Giovambattista, A. 140
Grimaldi, G. 174
Grinberg, T. 186
Grutzeck, M.W. 100, 147

Haimin, W. 167
Hall, D.J. 105
Halstead, W.J. 34
Hayes, T. 121
Heikkinen, A. 170
Helmuth, R.A. 183
Hilton, R.G. 23, 115
Hilsdorf, H.K. 157
Ho, D.W.S. 63
Hobbs, D.W. 61
Hooton, R.D. 53, 164
Hopkins, C.J. 75, 85, 154
Howell, L.H. 86
Hubbard, F.H. 78, 182
Huber, H. 79
Hums, I.D. 79

Idorn, G.M. 141
Ionescu, I. 185
Ish-Shalom, M. 186
Ispas, T. 185
Ivanov, Ya. 37

Jones, M.R. 182
Jones, P.K. 98
Jons, E.S. 124
Joshi, R.C. 32, 64, 83, 118, 120, 127

Kakizaki, M. 6
Kanitakis, I. 6
Karuks, E. 121
Kim, E.K. 173
Kirkby, G.A. 144, 171
Klaiber, F.W. 161
Klieger, P. 55, 150, 172
Kohno, K. 193
Komatsu, H. 193
Korac, V. 57
Kropp, J. 157
Kruger, J.E. 27, 59
Kuperman, S.C. 130

Lacey, R.A.C. 92
Laguros, J.G. 101
Lambert, G.H. 155
Lamond, J.F. 52, 139
Langan, B.W. 83, 120, 127
Lee, D.Y. 161
Lee, R.E. 75, 112, 154
Lenkei, M. 103
Lewis, R.K. 63

Luke, K. 99
Luoshu, G. 167

Maage, M. 145, 189
Mahmud, H.B. 168
Mailvaganam, N.P. 68
Majko, R.M. 108
Malek, R.I.A. 147
Malhotra, V.M. 71, 160
Manz, O.E. 58, 165, 180
Marion, A.M. 151
Martin, R.G. 23, 106
Marzouk, H.M. 66, 80
Massidda, L. 126
Mather, B. 5
McCarthy, G.J. 165
Mearing, M.A. 22, 30, 142
Mehta, P.K. 2, 51, 179
Meland, I. 146, 176
Mills, R.H. 149
Mings, M.L. 107
Mörtel, H. 79
München, Y.A. 79
Munday, J.G.L. 16, 40, 43, 60, 78, 182
Munn, R.L. 8, 56, 87, 91

Nagataki, S. 82, 173, 190
Nasser, K.W. 66, 80, 169
Natt, G.S. 64, 118
Nissoux, J.L. 67
Norholm, A. 25

Oberst, D.C. 114
Ogden, C. 95
Ohga, H. 82, 173
Ong, L.T. 16, 40, 43, 60
Osbaeck, B. 25
Okamoto, K. 191
Oswell, J.M. 118
Owens, P.L. 1, 26, 35, 47
Oztekin, E. 159

Paillere, A.M. 174
Papayianni, J. 166
Philleo, R.E. 4
Pierce, J.S. 33
Plowman, C. 9, 75, 90, 154
Plumat, M. 160
Popovics, S. 163
Proctor, R.T. 92

Raba, C.F., Jr. 22, 30, 115
Ramachandran, V.S. 125
Ramakrishnan, V. 19, 188
Rattanussorn, M. 147
Raverdy, M. 174
Ravina, D. 10, 14
Richards, R.G. 88
Riches, M.E.A. 95
Rivera, R.V. 138, 158
Roca, A. 133
Roper, H. 144, 171
Rosnerl, J.C. 29
Rossello, S.A. 84, 131
Rossouw, E. 27, 59
Rovira, J. 133
Roy, D.M. 99, 100, 103, 147
Rugen, M.A. 117
Ryan, W.G. 8

Saeki, N. 175
Samarin, A. 56, 135
Sanna, U. 126
Sawada, T. 119
Scanlon, J.M. 7
Schlorholtz, S. 102

Schubert, P. 18
Seeberger, J. 157
Sersale, R. 184
Shaw, J. 154
Shaw, K.L. 68
Shotter, J. 97
Silva, M.R. 130
Smith, G.R. 65
Smith, R.L. 22, 30, 117
Snel, A. 28
Spanjer, J.J. 94
Stoltenberg-Hansson, E. 143
Sturrup, V.R. 24, 53
Styron, R.W. 122
Sugita, H. 54
Swamy, R.N. 50, 70, 81, 155, 168

Takada, N. 175
Takano, T. 191
Tamas, F.D. 103
Tassios, T.P. 3
Tenoutasse, N. 151
Theodorakopoulos, D.D. 70
Tlustus, P.A. 19
Tse, E.W. 161
Tuutti, K. 128

Ujike, I. 190
Ukraincik, V. 57

Valenti, G.L. 184
van Dijk, J. 27
Vaquier, A. 153
Vazquez, E. 133
Venkataramanujam, P. 19
Verhasselt, A. 187
Virtanen, J. 72
vom Berg, W. 11

Waddicor, M.J. 35
Wainwright, P.J. 41, 76
Wakeley, L.D. 192
Walsh, P.F. 181
Ward, M.A. 42, 83, 120, 127
Warris, B. 69
Wesche, K. 11, 18
White, E.L. 103
Williams, J.T. 47
Woolley, G.R. 48, 75, 89, 154
Wong, L.B. 43
Wu, D.K. 136

Yamato, T. 54
Yasuda, M. 119
Yuan, R.L. 44, 62, 136

Zacharieva, S. 37